

**AMENDMENTS TO THE DRAWINGS:**

The attached nineteen (19) sheets of drawings include changes to Figures 1-17. These sheets, which include Figures 1-17 replaces the original thirteen (13) sheets including Figures 1-17. The drawings have all been amended to remove Japanese characters and to replace them with their English equivalents. Also, Figure 1 has been additionally amended to include character reference "PT," which had been previously omitted. Figures 2, 8, 13, 14 and 15 have been amended so that character references used to designate more than one different part in the drawings have been replaced as necessary in accordance with 37 C.F.R. § 1.84(p).

The present amendment adds no new matter to the drawings.

Attachment: Nineteen Replacement Sheets

Thirteen Annotated Sheets showing changes.

Annotated

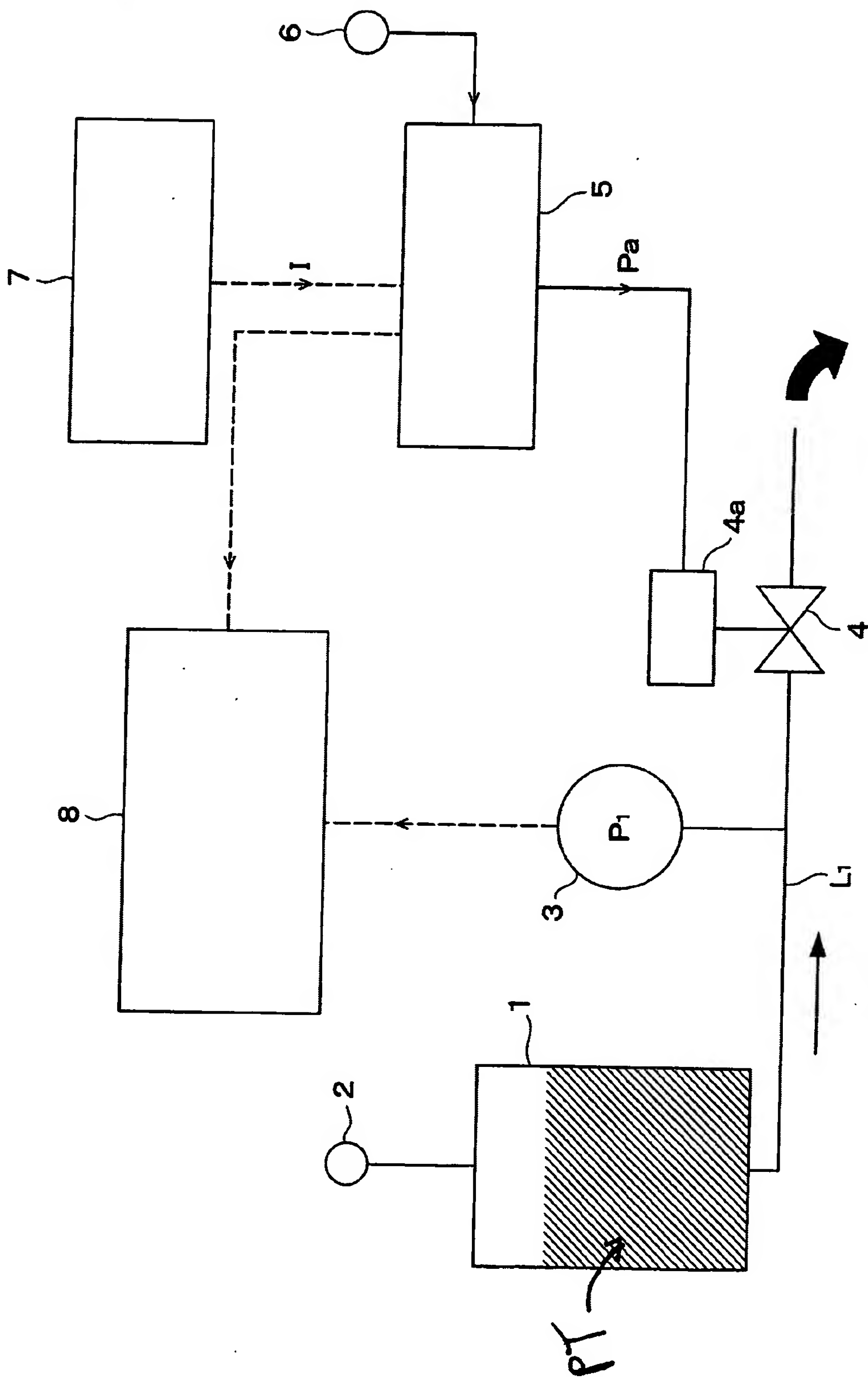


FIG. 1

Annotated

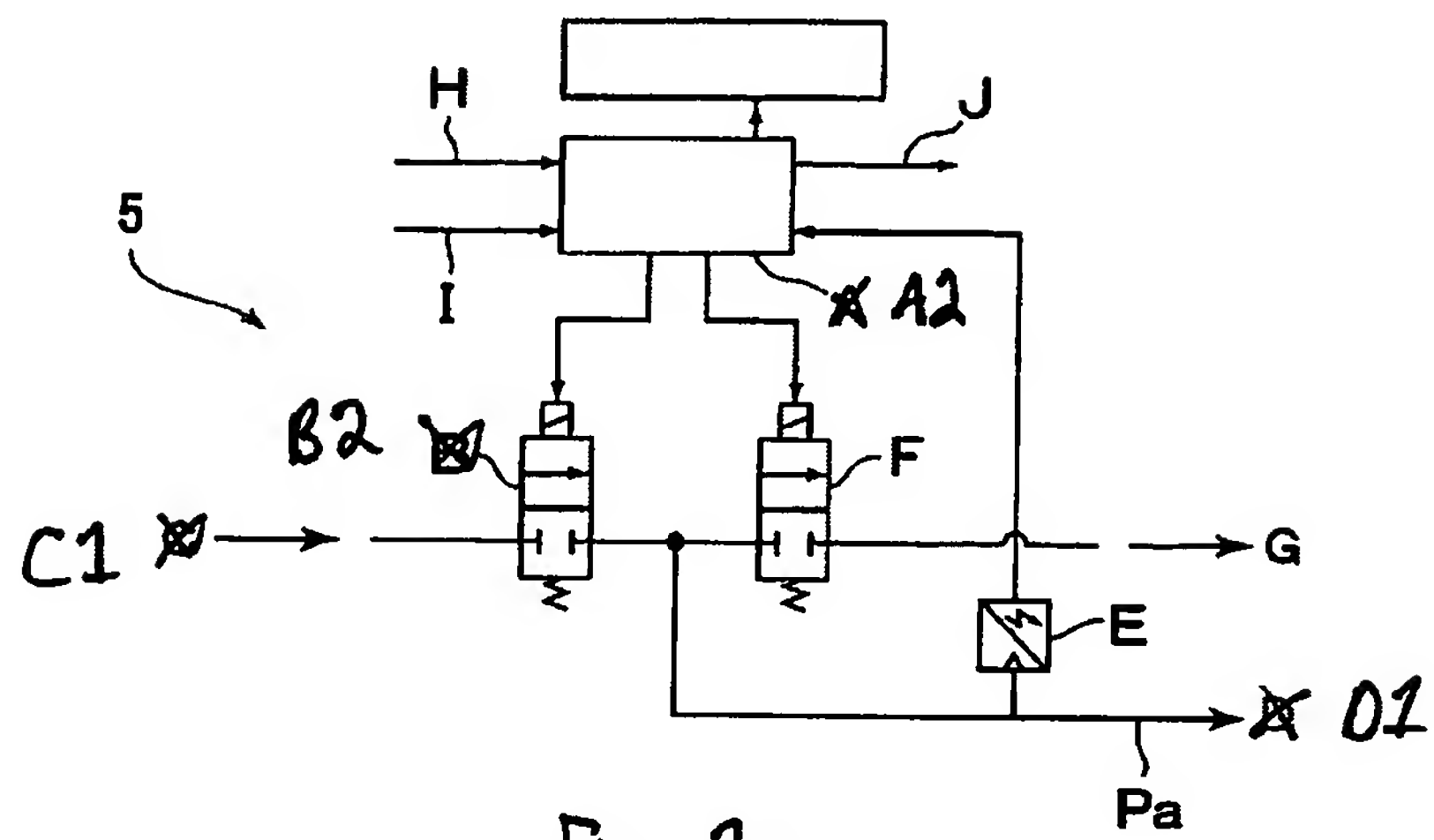


Fig. 2a

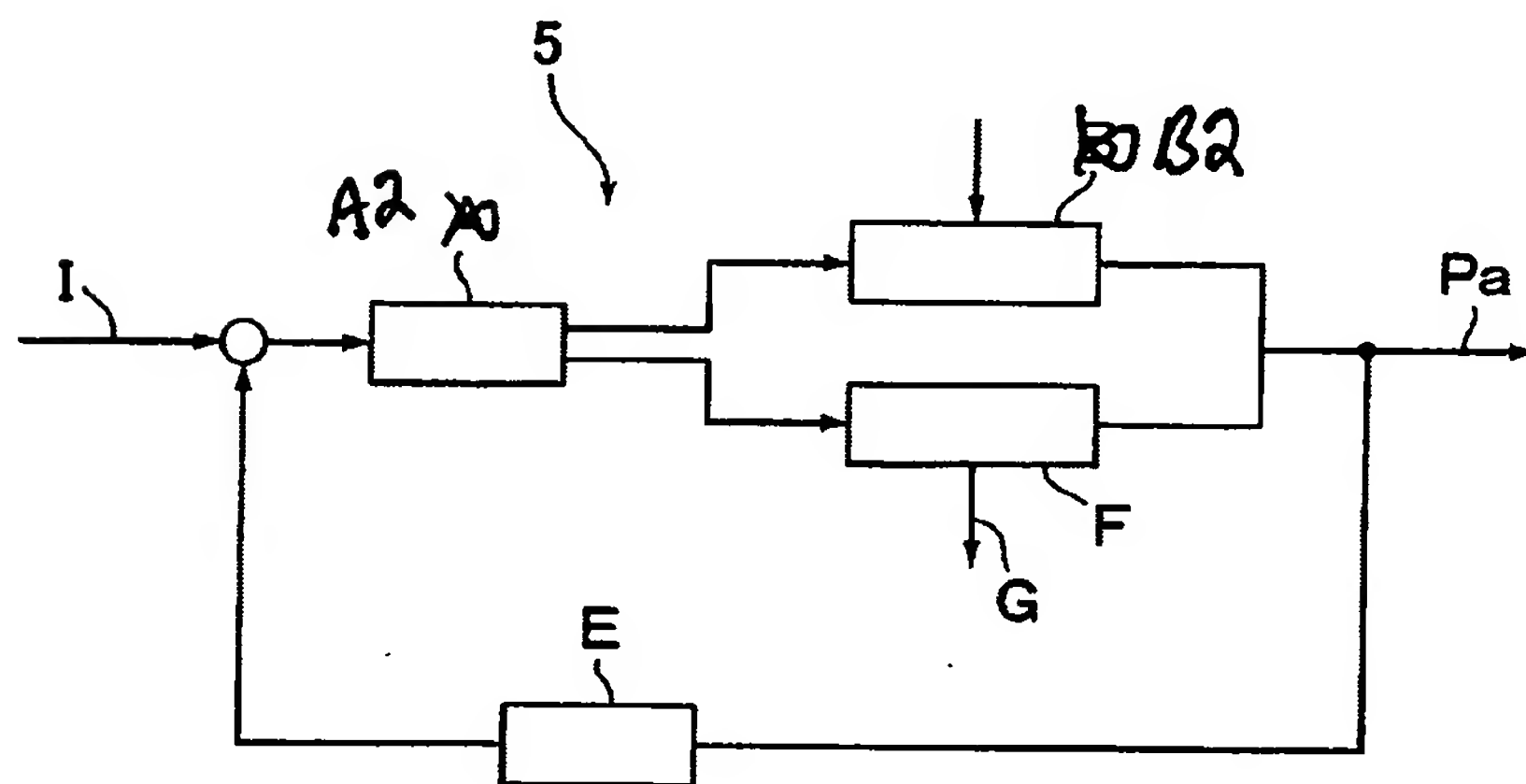


Fig. 2b

Annotated

[X3]

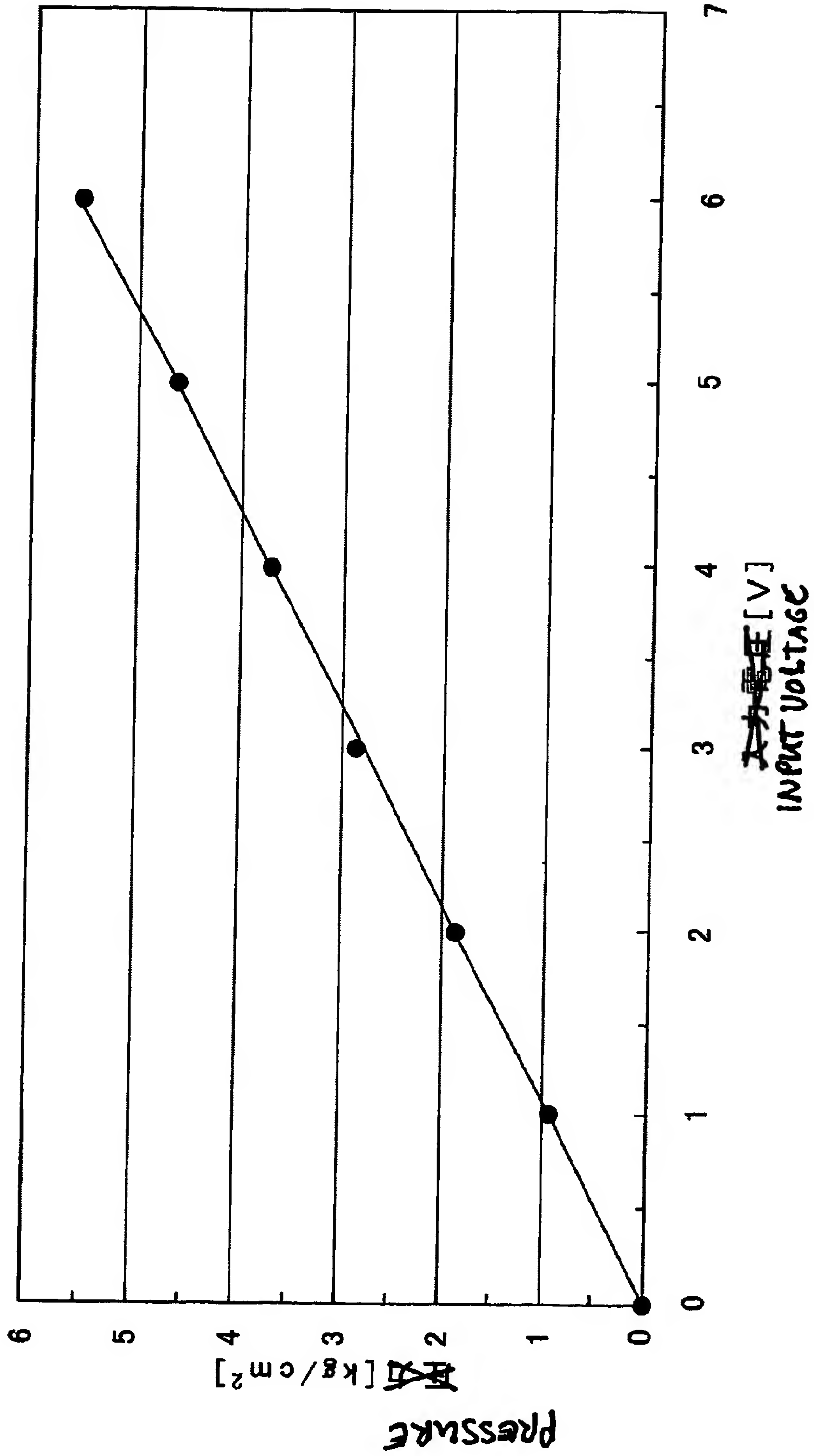


Fig. 3

Annotated



~~アクチュエータ圧力~~  
ACTUATOR  
PRESSURE

~~空気井上流配管振動~~  
PIPE VIBRATION  
UPSTREAM OF  
PNEUMATIC  
Valve

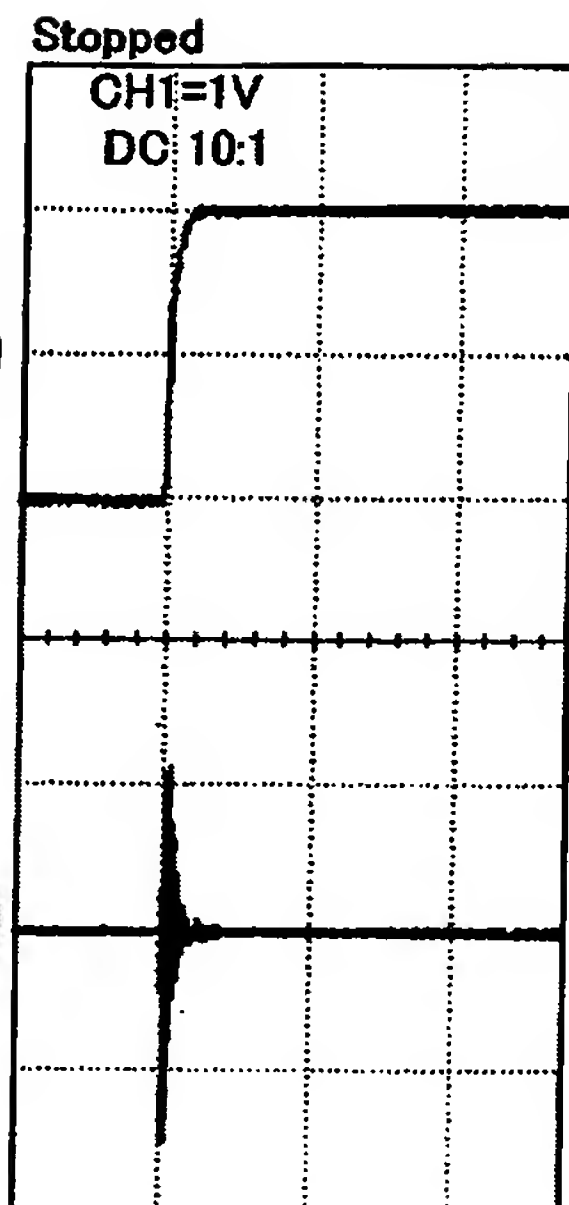


Fig. 4a

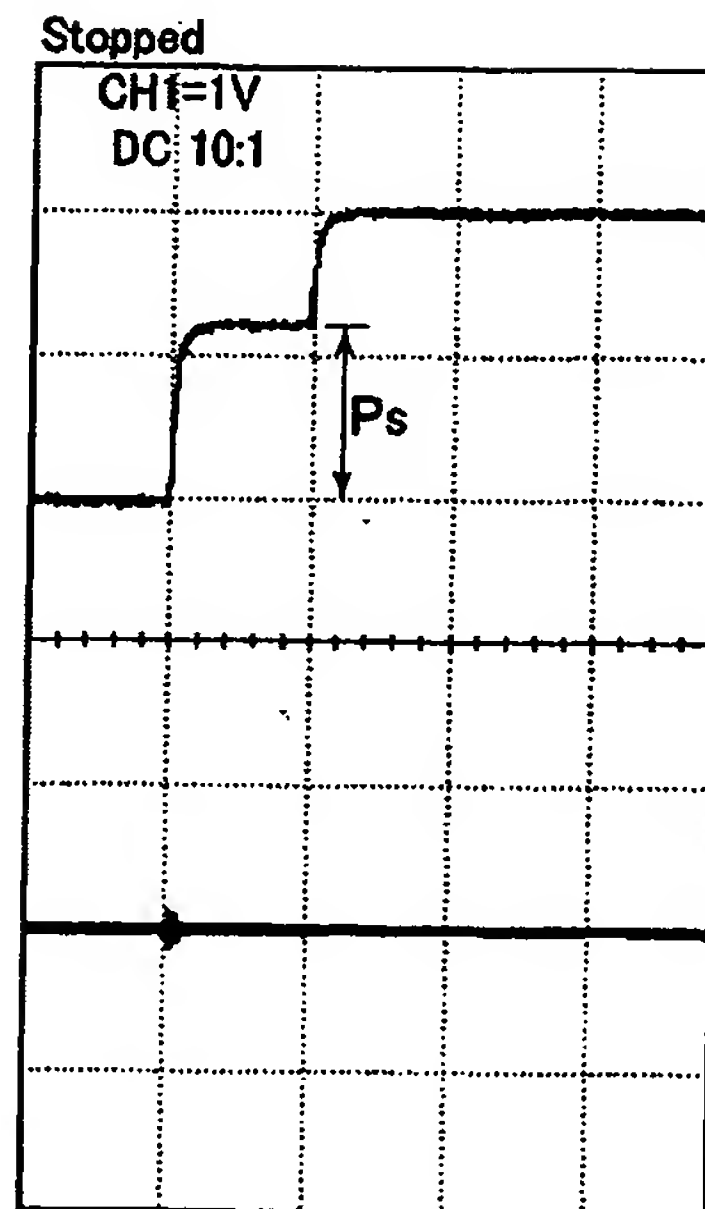
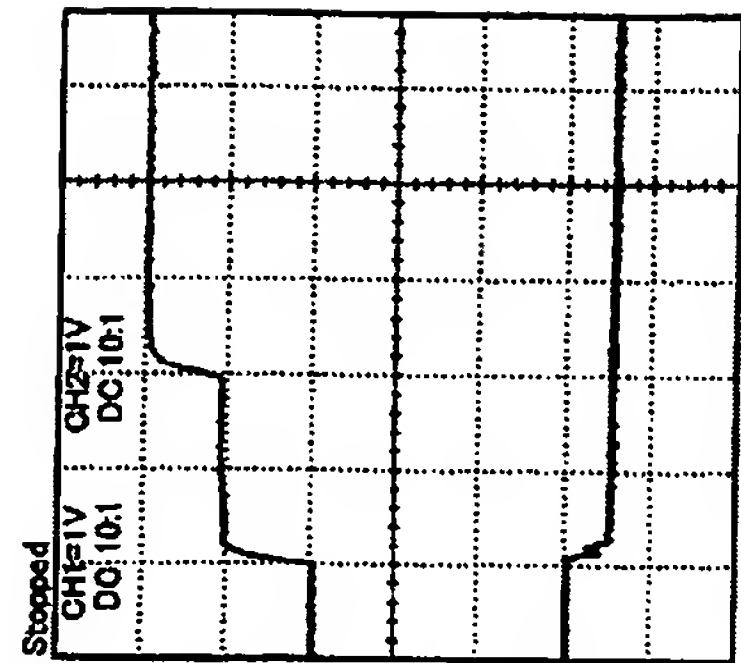


Fig. 4b

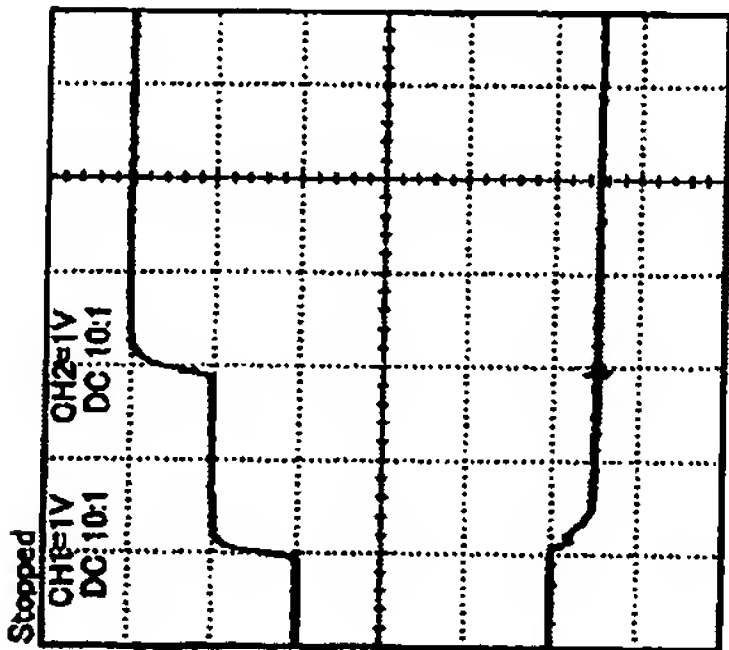
Annotated



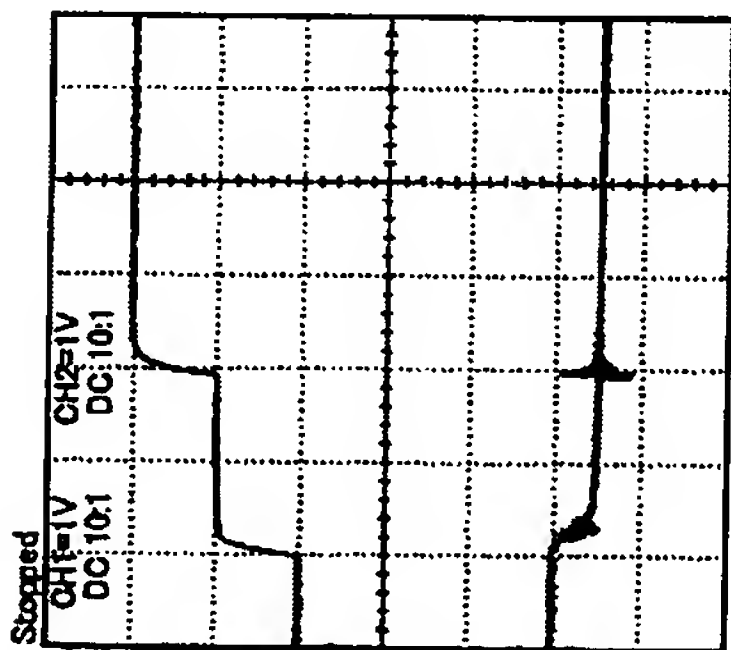
(b)



(b)



(a)



アクチュエータ圧力  
ACTUATOR PRESSURE  
流体圧力  
FLUID PASSAGE  
PRESSURE

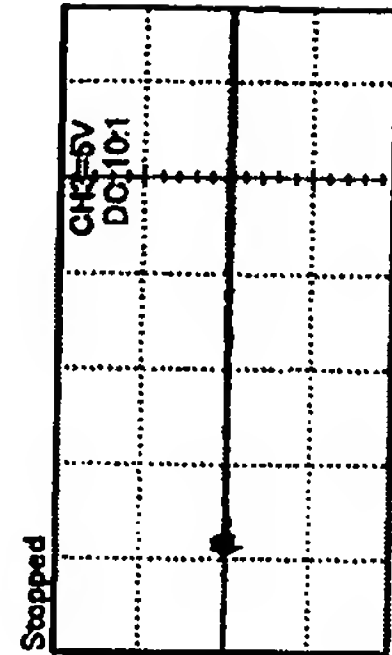


fig. 5c

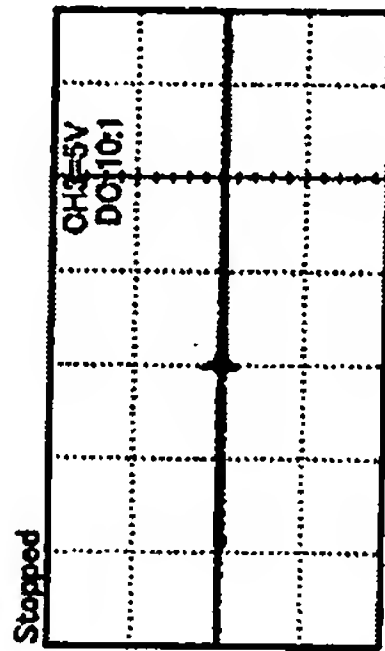


fig. 5b

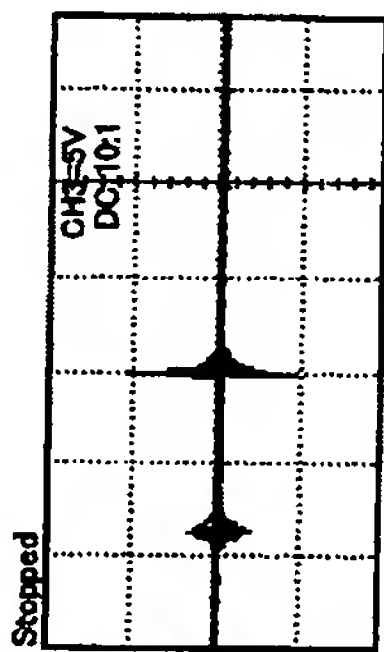


fig. 5a

振動(上流)  
VIBRATION  
(UPSTREAM)

Annotated

~~6~~

~~空気圧~~  
~~アクチュエータ圧力~~  
 AIR ACTUATOR PRESSURE

~~液体ライン圧力~~  
 FLUID PASSAGE PRESSURE

~~配管振動(上流)~~  
 VIBRATION (UPSTREAM)

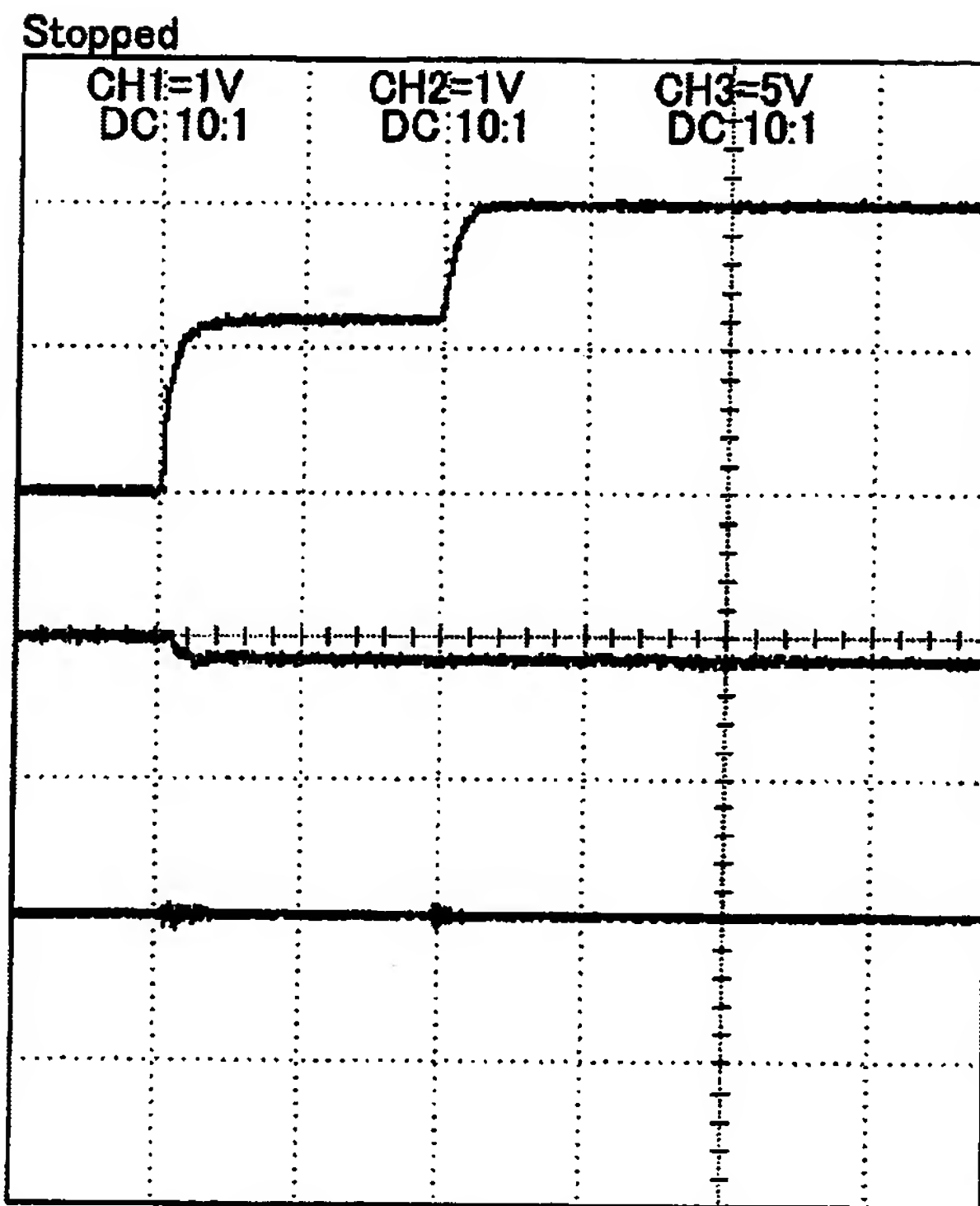


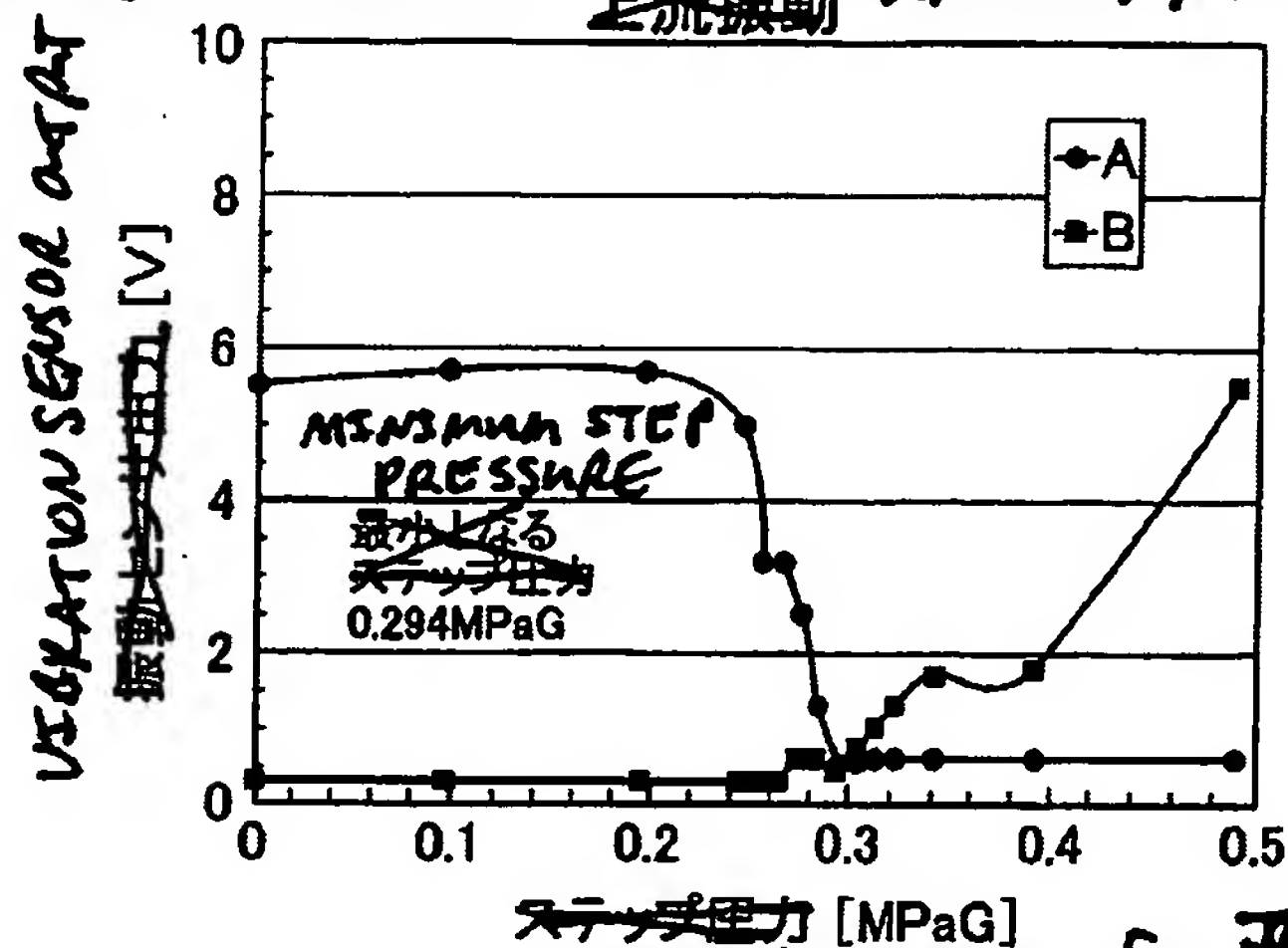
Fig. 6

7/13  
Annotated

~~TANK PRESSURE~~

~~タンク圧力~~: 0.098MPaG

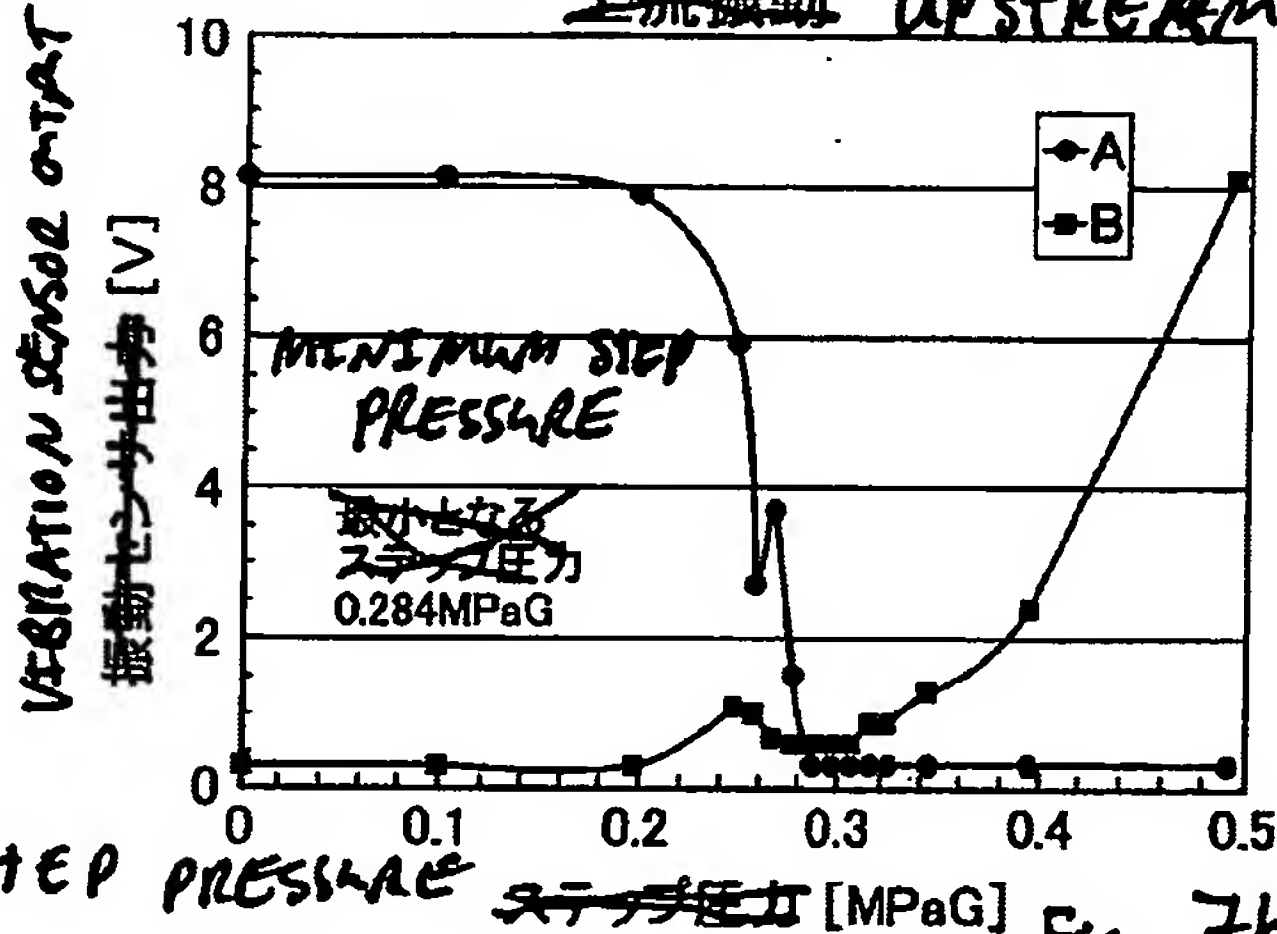
~~上流振動~~ UPSTREAM VIBRATION



~~TANK PRESSURE~~

~~タンク圧力~~: 0.196MPaG

~~上流振動~~ UPSTREAM VIBRATION



STEP PRESSURE ~~ステップ圧力~~ [MPaG] Fig. 7b

~~TANK PRESSURE~~

~~タンク圧力~~: 0.294MPaG

~~上流振動~~ UPSTREAM VIBRATION

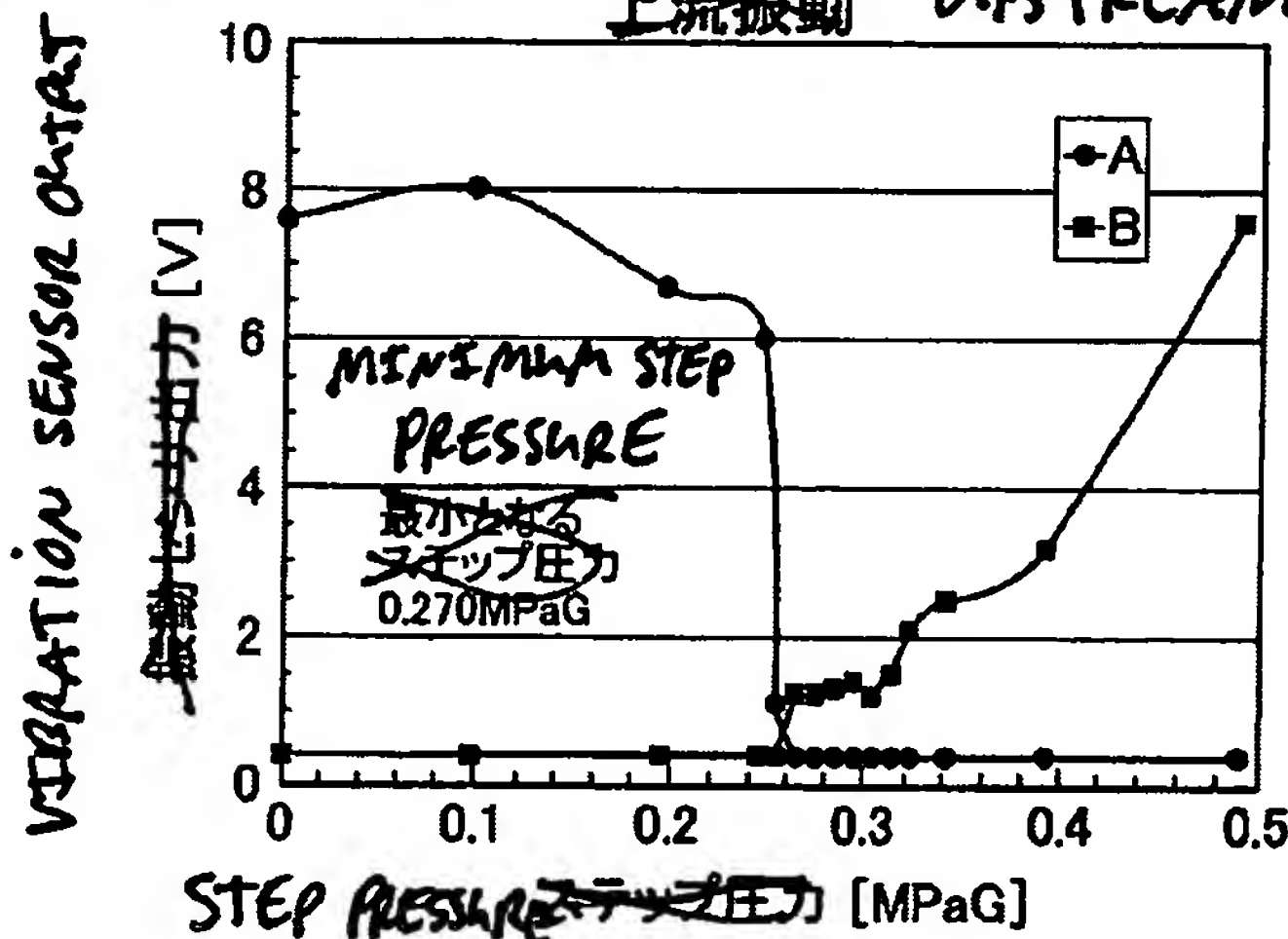
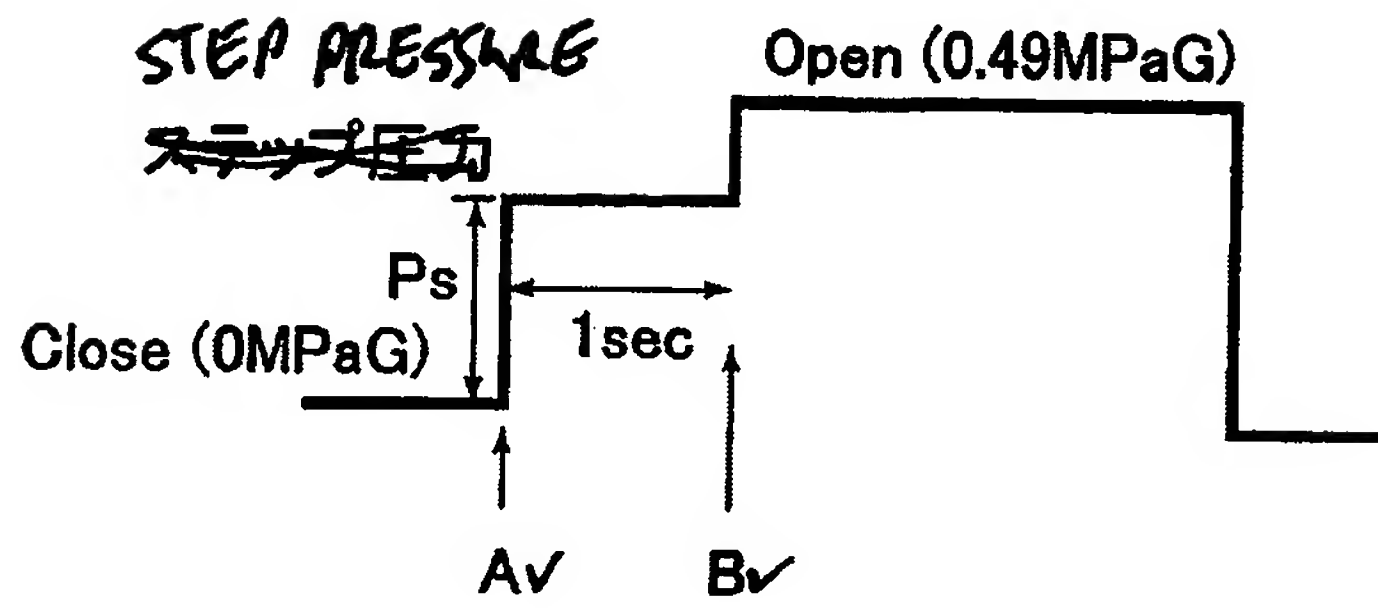


Fig. 7c



Annotated

~~Fig. 8~~

VIBRATION SENSOR

~~振動センサ~~

Fig. 8

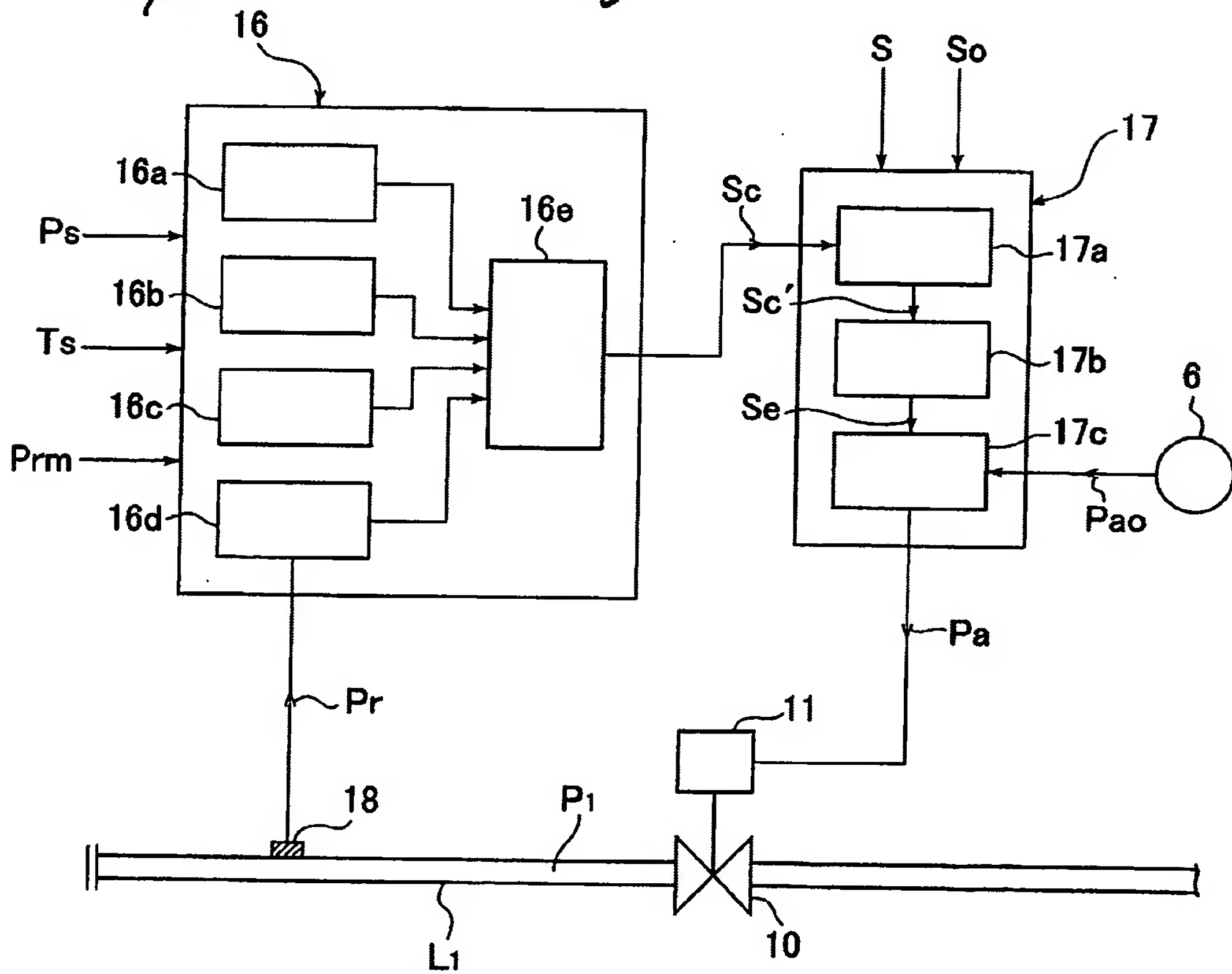


Fig. 9

Annotated  
~~10~~

~~10~~

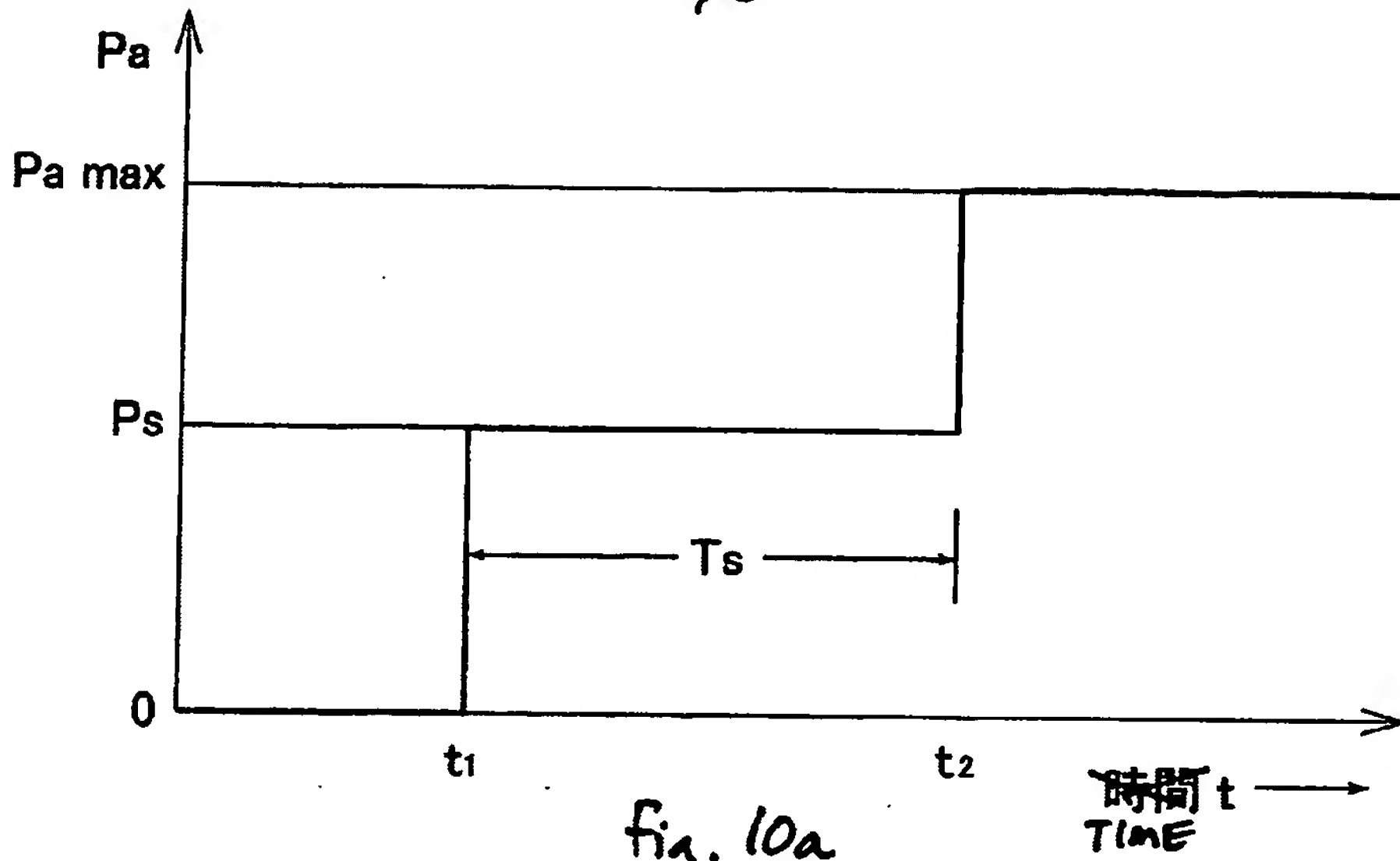


Fig. 10a  
~~10~~

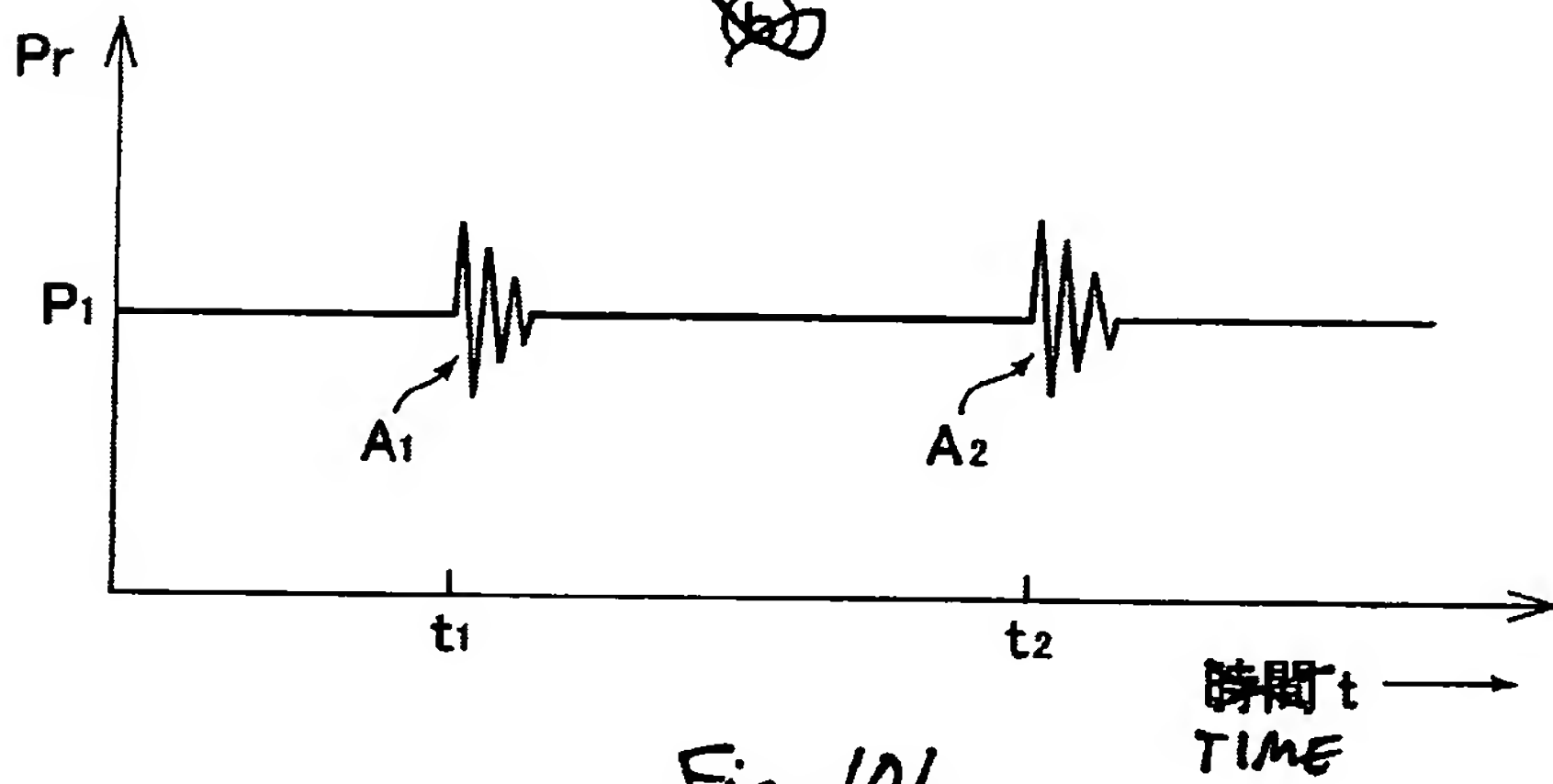


Fig. 10b

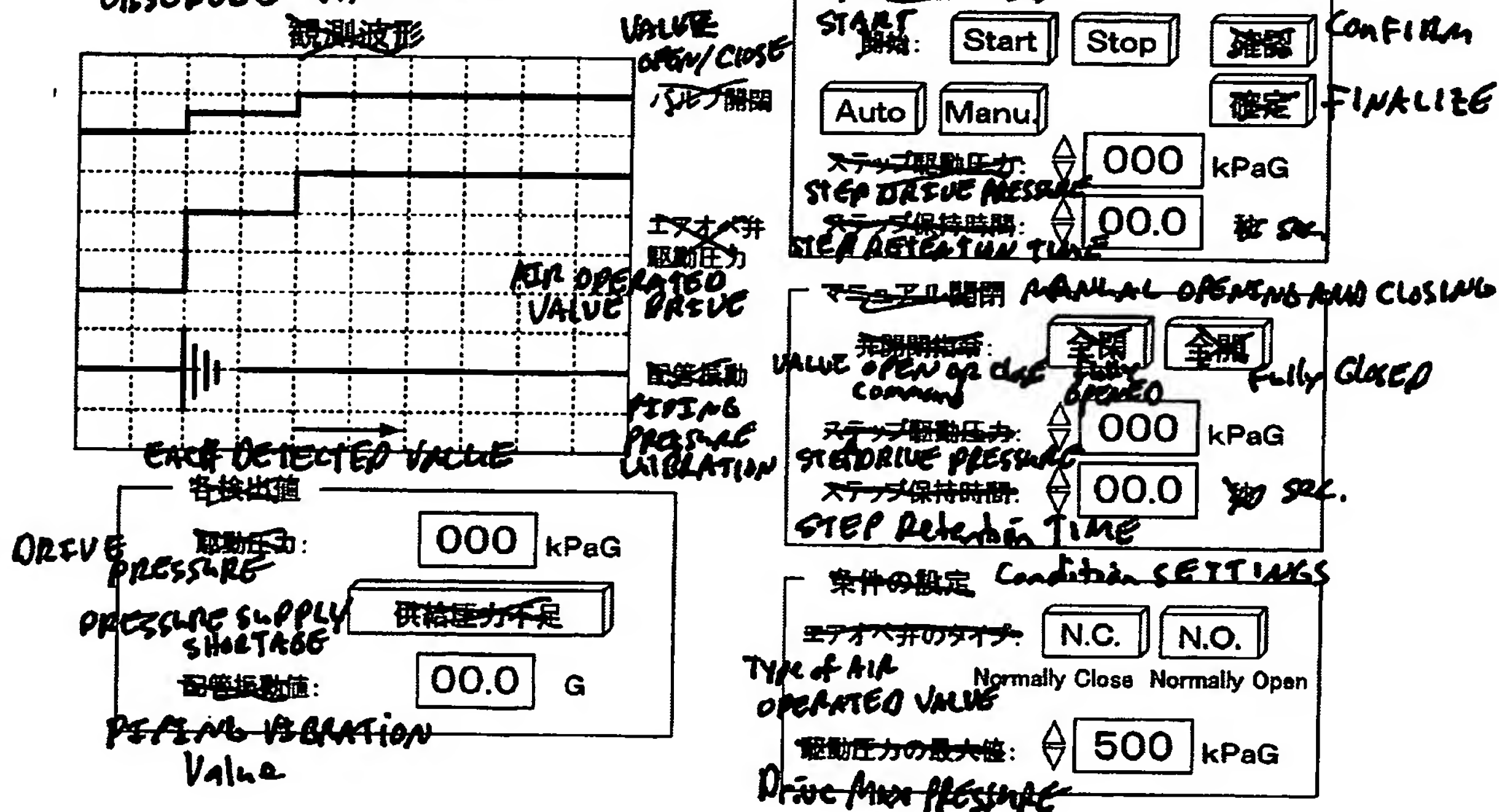
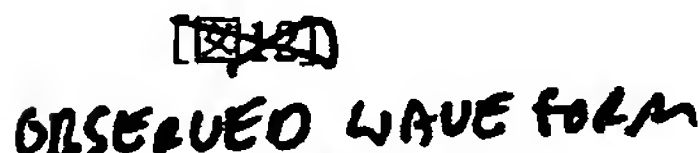


Fig. 12

Annotated

図13

POWER SOURCE

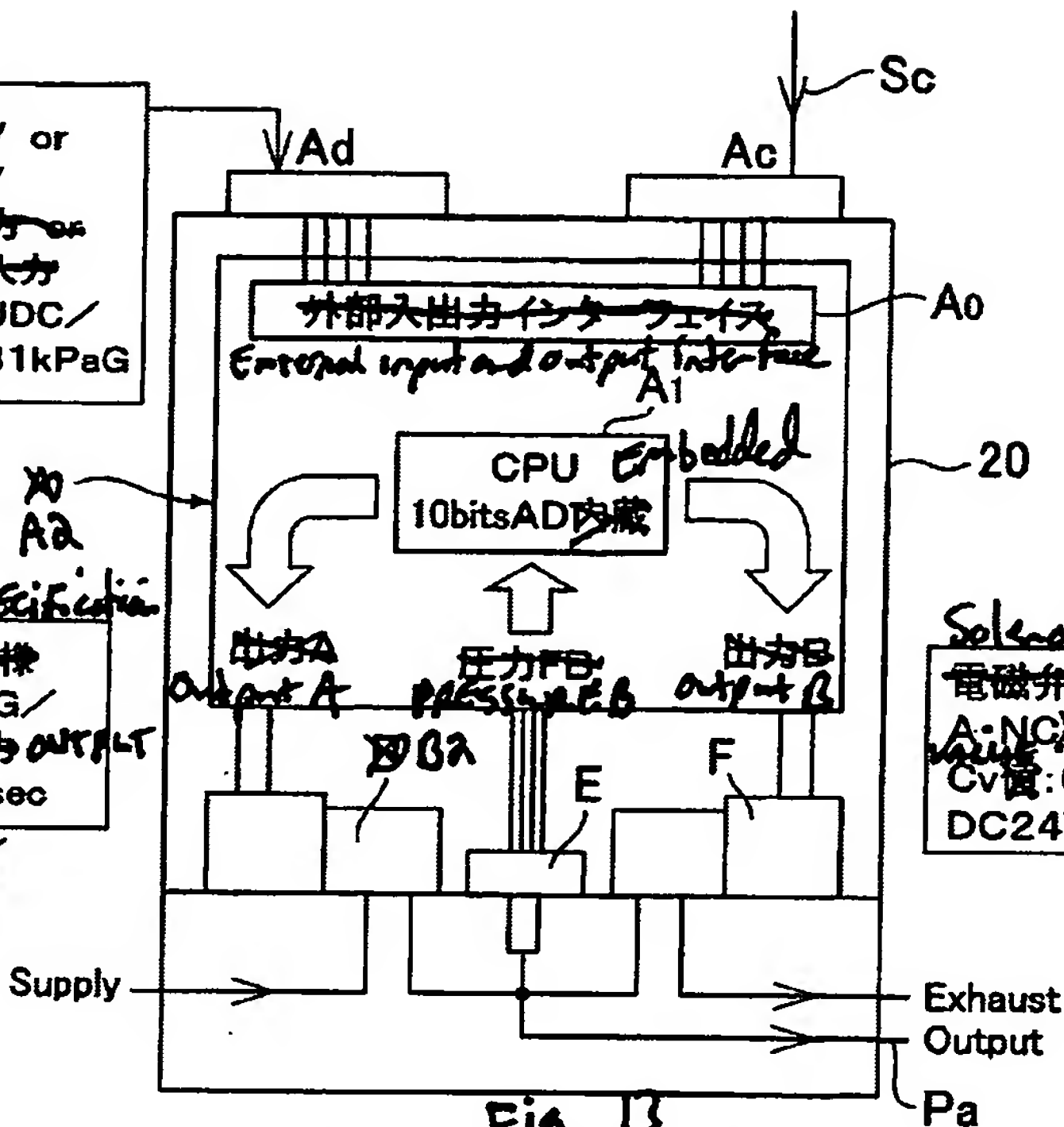
供給電源: DC24V or DC12V  
開閉信号: 電圧入力 or 無電圧入力  
圧力モニタ: 0~5VDC / 0~981kPaG  
PRESSURE MONITOR

OPEN and Close  
signals: Voltage  
input or No voltage  
input

PRESSURE SENSOR SPECIFICATION

圧力センサ仕様  
0~981 kPaG /  
0~90 mV出力 OUTPUT  
応答性: 約1msec

RESPONSIVENESS: about



Solenoid valve specification

電磁弁仕様  
A: NC型 B: NO型  
Cv値: 0.008  
DC24V or DC12V

Fig. 13

図14

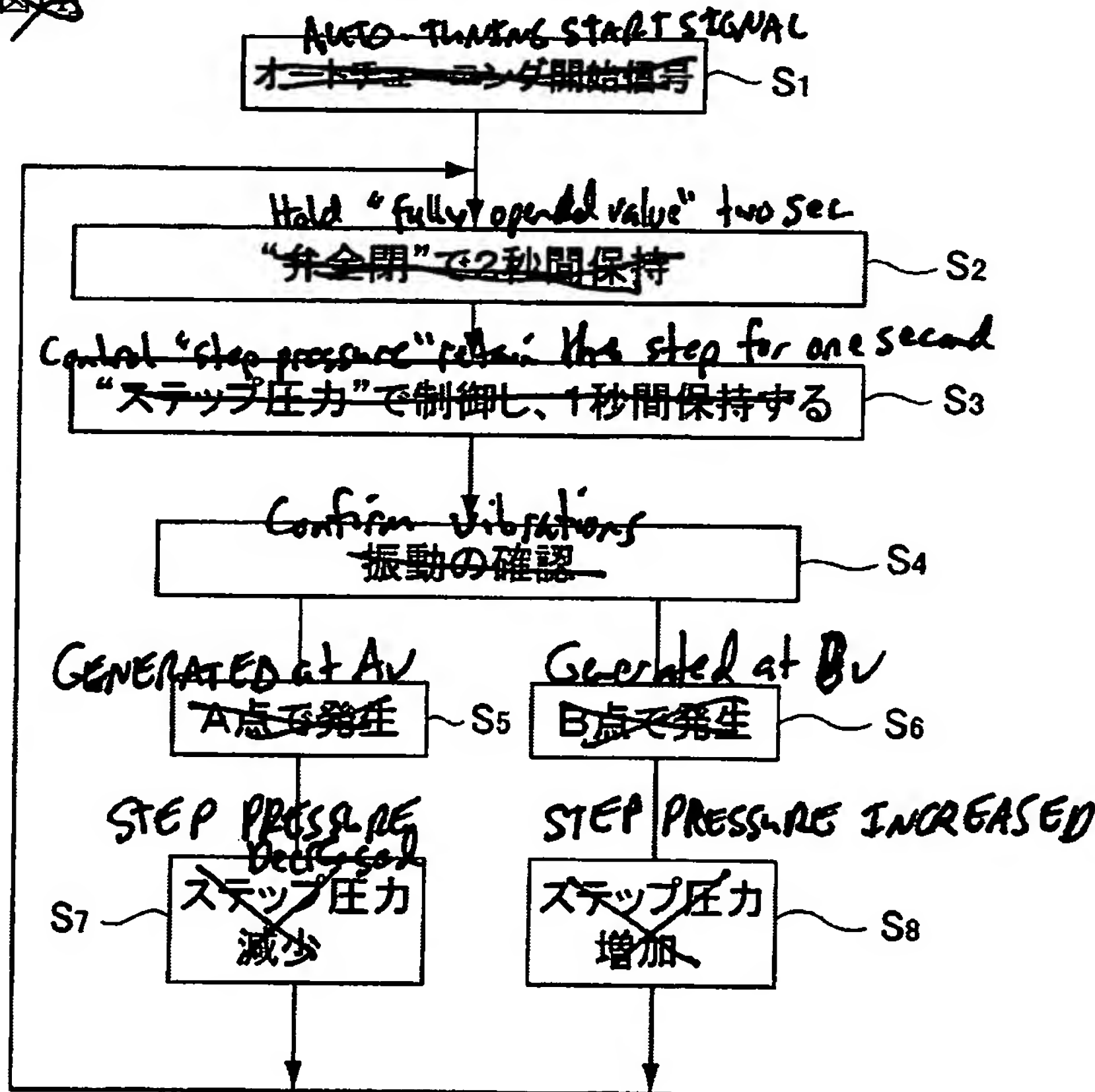


Fig. 14

Annotate

~~[15]~~

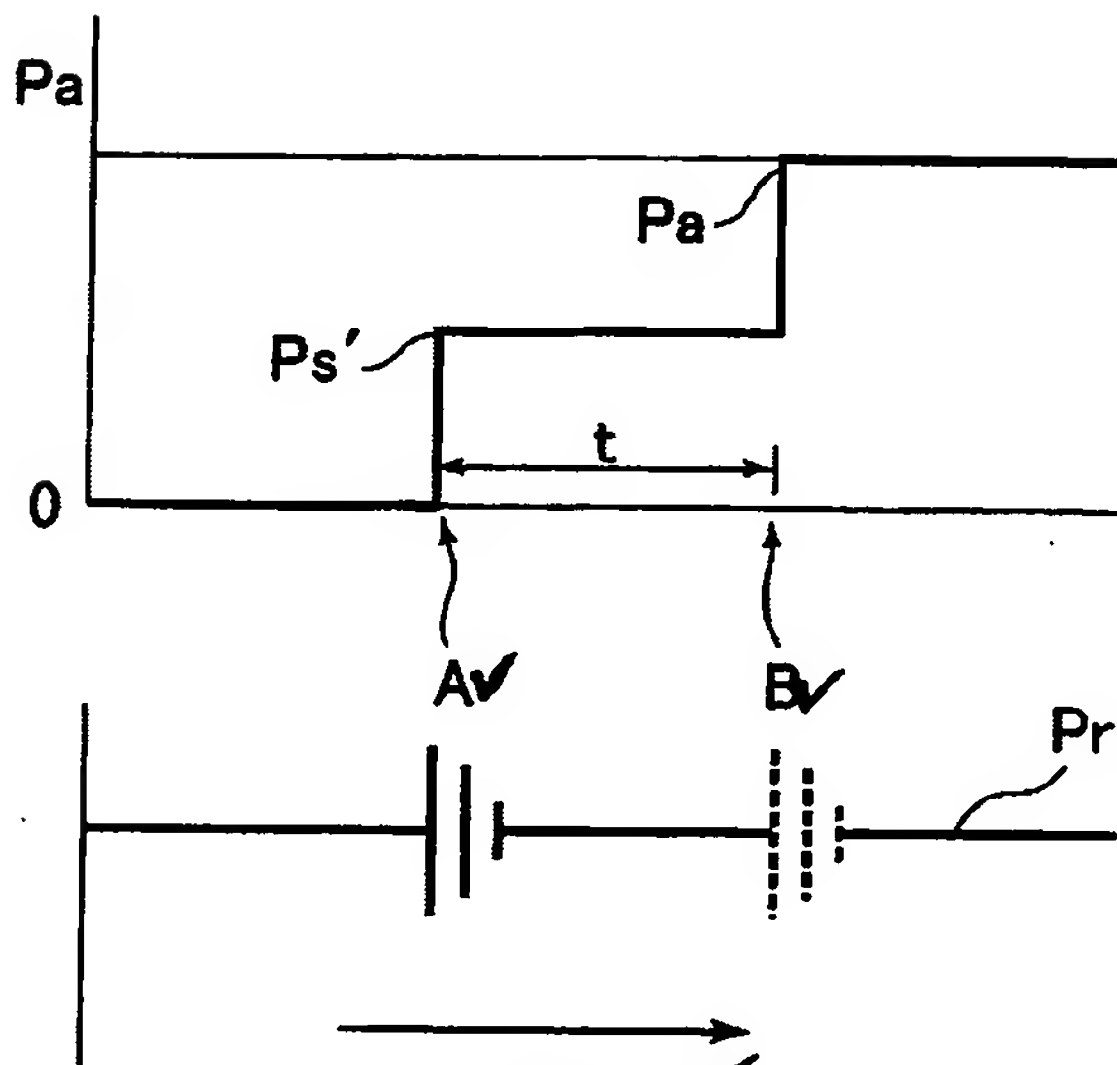
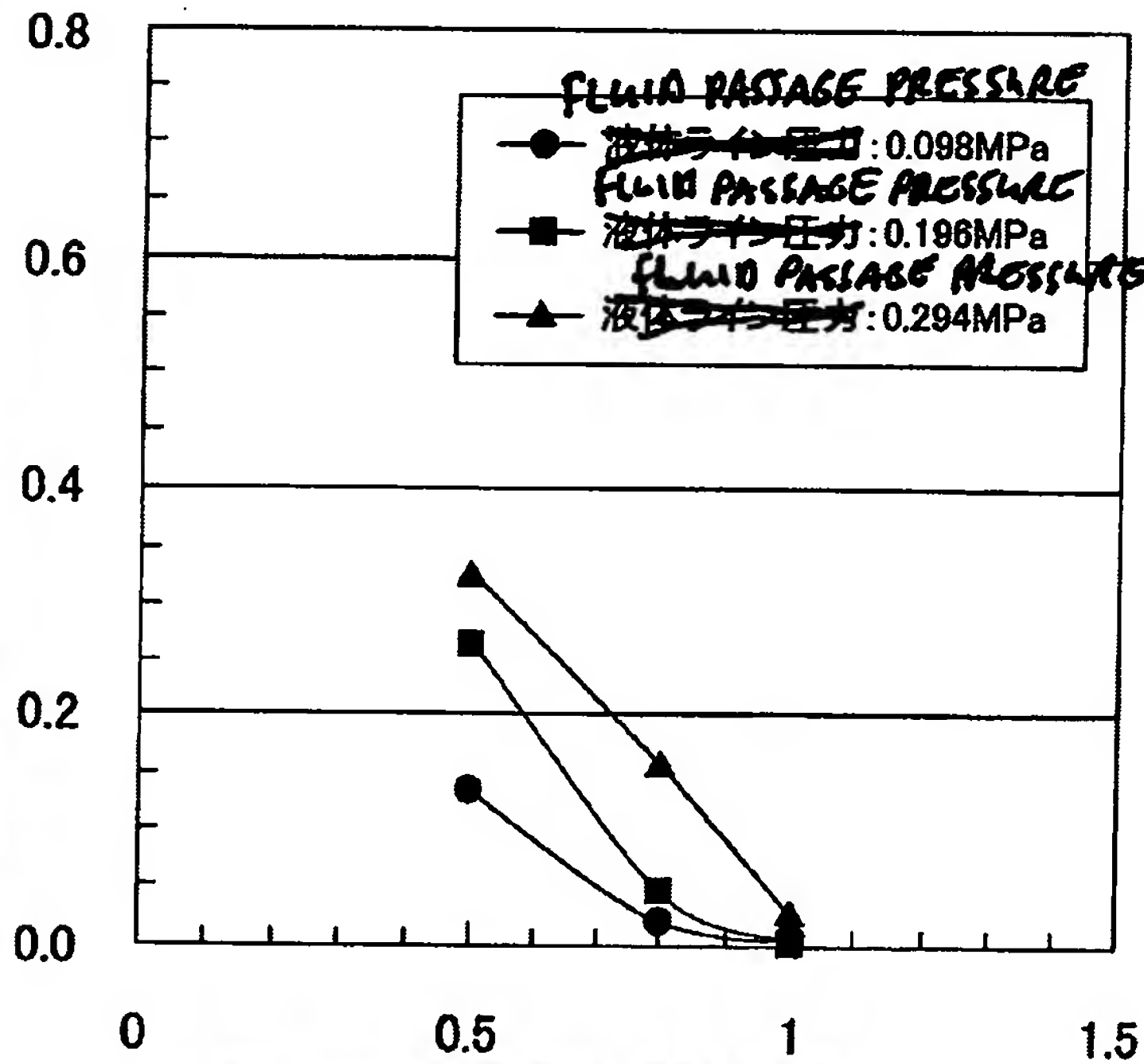


Fig. 15

AN INCREASE IN FLUID PASSAGE PRESSURE

~~液体ライン圧力上昇  $\Delta P$  [MPa]~~



ステップ圧力保持時間 [ sec ]

STEP PRESSURE RETENTION TIME

Fig. 16

Annotated

~~[17]~~

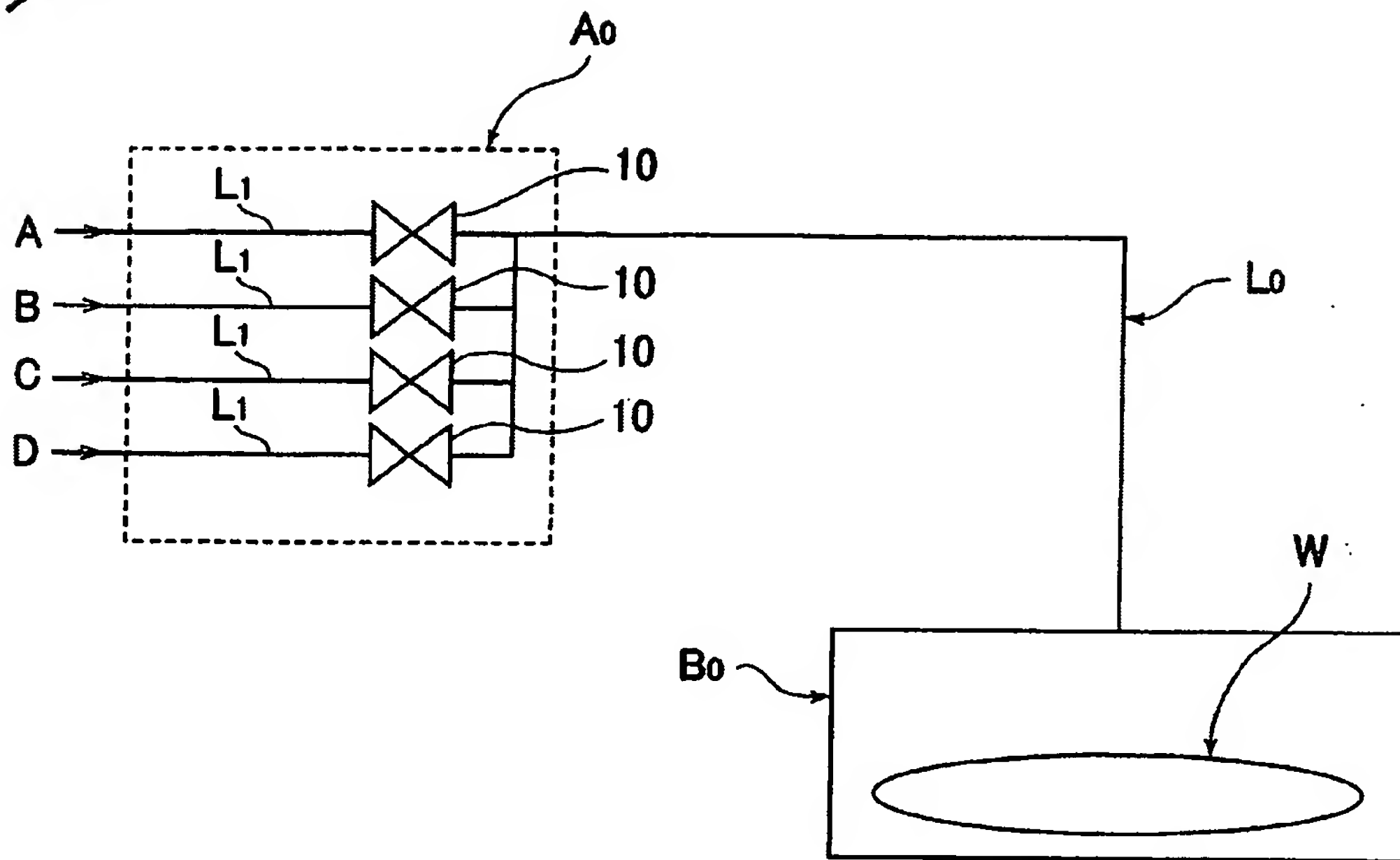


Fig. 17

**REMARKS**

The specification has been amended to incorporate the International and Japanese priority applications by reference, and to improve grammar, change several character references used in the drawings, and to incorporate certain subject matter contained in the original drawings. A substitute specification in compliance with 37 C.F.R. §1.125 is attached. The attached substitute specification contains no new matter.

The Abstract has been amended to comply with 37 C.F.R. § 1.72. The drawings have been amended to replace Japanese characters with their English equivalents and to comply with 37 C.F.R. § 1.84(p). The claims have been amended to delete multiple dependencies and to place them in better form for examination. The present amendment adds no new matter to the application.

Accordingly, it is believed that the application is in good condition for examination. The below-signed attorney for Applicants welcomes any questions.

Respectfully submitted,

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## SPECIFICATION

# METHOD FOR WATER HAMMERLESS OPENING OF FLUID PASSAGE, AND METHOD FOR SUPPLYING CHEMICAL SOLUTIONS AND DEVICE FOR WATER HAMMERLESS OPENING FOR WHICH THE METHOD IS USED

[0000] This is a National Phase Application in the United States of International Patent Application No. PCT/JP2005/000264 filed January 13, 2005, which claims priority on Japanese Patent Application No. 2004-011497, filed January 20, 2004. The entire disclosures of the above patent applications are hereby incorporated by reference.

## Field of the Invention

[0001] The present invention is concerned with improvements in a water hammer prevention system with which the water hammer effect is completely prevented ~~when at the time of~~ promptly opening of a fluid passage, and is more ~~specifically~~ ~~concretely~~ concerned with a method for water hammerless opening of a fluid passage, a method for feeding chemical solutions, and a device for water hammerless opening for which the method is used so that the fluid passage is opened quickly and surely without causing the occurrence of a water hammer effect on the upstream side of the fluid passage irrespective of the degree of the fluid pressure involved.



### Background of the Invention

[0002] It has been widely known that when a passage through which a liquid, such as water or the like, passes is abruptly closed, there occurs the so-called water hammer with which the pressure rises inside the passage on the upstream side of the closed point in a vibratory manner~~with vibrations~~, thereby causing~~thus~~ various problems such as the breakdown of devices or instruments connected to the passage due to the~~being caused by~~ said water hammer.

[0003] Thus, various techniques have been developed to prevent the occurrence of a water hammer.\_\_\_\_

4

However, these techniques basically employ either one of the following methods, that is,; (1) the time for closing a fluid passage is~~being set to be~~ slightly longer, or (2) the vibrating pressure generated inside of the passage is~~being~~ released to the outside by opening a~~the~~ bypass passage, or is~~being~~ absorbed by a separately installed~~the accumulator separately installed~~. The former method is found to be time-consuming~~taking~~ for closing the fluid passage, thus resulting in failure to~~in meeting with~~ the need for~~of~~ the prompt closing of the passage, while according to the latter method, the added costs for the bypass passage or the accumulator attachments is~~become~~ too high.

[0004] The afore-mentioned issues regarding the water hammer effect have been discussed in those industrial fields where ~~the fluid~~ involves~~with~~ a relatively large flow quantity ~~is involved~~. In recent years, however, in ~~the~~ fields where a small flow quantity is involved~~dealt with~~, for example, in a field where wafer cleaning in semiconductor manufacturing or chemical products manufacturing

are ~~encountered~~ dealt with, it has become a very important to prevent the occurrence of a ~~issue that~~ water hammer is ~~prevented at the time of urgent closure of~~ supplied the fluid in order to ~~be supplied from the view points of~~ improving the maintenance of facilities, and the ~~improve~~ product quality, and, further, achieve upgrading of so-called throughput characteristics in the manufacturing process.

[0005] Patent Document 1: Toku-Kai-Hei No.7-190235 Public Bulletin

Patent Document 2: Toku-Kai No.2000-10602 Public Bulletin

Patent Document 3: Toku-Kai No.2002-295705 Public Bulletin

[0006] On the other hand, the inventors of the present invention have developed and disclosed techniques to solve the afore-mentioned problems related to conventional techniques for ~~to~~ preventing the occurrence of the water hammer effect, namely ~~that is~~, (1) \_-

2

not being able to cope fully with urgent passage closure without ~~the presence of urgency by a measure~~ basically to setting a slightly longer a closing time of the fluid passage ~~slightly longer~~, and (2) not being able to cope fully with the rising facilities' costs incurred of facilities to be attached by a adding measures that basically ~~to~~ absorb or release the vibrating pressure. T, thus, the present invention making it possible to abruptly close at a fluid passage quickly and surely at low cost and being abruptly closed without generating a water hammer at a low cost, quickly and surely.

\_\_\_\_\_In particular Namely, the said techniques of the present invention allow a fluid passage to be abruptly closed without the occurrence of a water hammer

and, in an extremely short lapse of time (for example, within 1000\_m-sec), by performing the closure of a valve provided on the fluid passage by means of the multi-step closing operations. Also, thesaid techniques of the present invention determine the conditions for closing thea valve in advance of actual closure, and in order to make it possible for the fluid passage to ~~be~~ closed without a water hammer forming, ~~in advance~~ by actually conducting valve closing tests so that the actuator of the valve body is operated by anthe electro-pneumatic conversion device in which ~~said~~ valve closing conditions are stored. Thus, water hammerless closing of the fluid passage isbeing achieved quickly and surely.

#### Disclosure of the Invention

##### Object of the Invention

[0007] W~~Techniques of water hammerless closing techniques~~ for a fluid passage have previously been developed by inventors of the present invention and allow the fluid passage to be abruptly closed, quickly and surely, without causing a water hammer effect ~~quickly and surely~~, thus achieving excellent, practical effects.

[0008] \_\_\_\_\_ However, in recent years, in the fields such as the semiconductor \_-

3

manufacturing facility industry, the chemical and pharmaceutical industries, and the like, there hashave been a strongly desired to reliably prevent thethat water hammer effect at the time when the fluid passage is abruptly opened andis

~~surely prevented~~ not only at the time when the fluid passage is abruptly closed, but also ~~at the time when the fluid passage is abruptly opened~~. This means that the conventional measure ~~for~~ preventing a water hammer at the time of abrupt closure of the fluid passage has not been found ~~not~~ to be sufficient. The reason is that when a water hammer occurs at the time of opening the fluid passage, various difficulties, such as moving of particles into the fluid passage and the like, arise~~come up~~.

[0009] Due to the recent trend wherein~~that the~~ semiconductor cleaning devices, and the like, employ the cleaning equipment with which wafers are now treated one by one (a single wafer processing cleaner), it has become an important issue ~~not only that~~ quality improvements in the liquid supply system are achieved, but also that the time required for each process of cleaning is shortened to improve so-called throughput characteristics. Furthermore, with use of the afore-mentioned new treatment-~~type~~ semiconductor manufacturing facility, it becomes inevitable that the frequency of valves opening~~being opened~~ and closing~~closed~~ increases because wafers are singly~~treated singly~~. Therefore, there is a need for stable ~~or~~ water hammerless valve opening and closing methods~~are needed~~. As such, it has become a strict~~severe~~ requirement that the liquid supply system does not cause pressure fluctuations while wafers are processed.

[0010] It is an object of the present invention to solve the afore-mentioned problems encountered with semiconductor manufacturing facilities, cleaning equipment and the like, and to provide a method for water hammerless opening of the fluid passage, and a method for the supply of liquid, ~~supply~~ and a device

for water hammerless\_–

4

opening, for which the method is used so that the fluid supply passage is surely and abruptly opened in a state of water hammerlessness.

Summary of the Invention Means to Achieve the Object

[001109] Inventors of the present invention have ~~conceived~~~~come up with~~ an idea of how to open a valve by ~~at~~ the multi-step method, in which a valve body of the valve blocking the passage is rapidly moved to ~~at~~ the prescribed position before reaching the full opening position, and then, the valve body is moved to the full opening position after ~~at~~ the short lapse of time. ~~A,~~ and at the same time, a number of analytical tests were conducted ~~by the inventors~~ on the mechanism of how ~~a~~ water hammer occurs by ~~employing~~~~using~~ ~~the said~~ method ~~of the present invention~~ for opening the valve. ~~False,~~ ~~rom~~ with the results of the afore-mentioned tests, ~~the~~ inventors of the present invention have learned how to prevent the occurrence of ~~the~~ water hammer ~~effect~~ by making the stopping position of the valve body at ~~at~~ the first step come within ~~at~~ the specified range when the valve is ~~first~~ opened.

[00120] The present invention has been created based on the afore-mentioned findings. The present invention, in accordance with a first method embodiment~~as claimed in Claim 1,~~ is fundamentally ~~so~~ constituted so that, with the method by which the fluid passage is made open by means of the actuator operating type valve provided on the fluid passage having ~~at~~ the nearly constant pressure inside the pipe passage, first the valve body is moved toward the



direction of the valve opening by increasing or decreasing to the prescribed set value the afore-mentioned driving input to the actuator ~~being increased or reduced to the prescribed set value~~, and the driving input to the actuator is held at the afore-mentioned set value for a short period of time, and then, the said driving input is further increased or reduced \_-

5

to place make the valve in a state of full opening, thus the fluid passage is being opened without causing a water hammer.

[00134] The present invention in accordance with a second method embodiment, which further modifies the first method embodiment, ~~as claimed in Claim 2 according to Claim 1~~ is so-made so that the valve is a normally closed and pneumatic pressure operating type diaphragm valve, or a normally closed and pneumatic pressure operating type diaphragm valve which is of the fixed capacity type with the inner capacity of the valve not changing being changed when the valve is operated, ~~is employed for a valve~~.

[00142] The present invention in accordance with a third method embodiment, which further modifies the first method embodiment, ~~as claimed in Claim 3 according to Claim 1~~ is so-made so that the time for holding the driving input to the actuator ~~being held~~ at the set value for a short period of time is made to be less than 1 second, and the pressure rise value of the fluid passage is made to be within 10% of the pressure value before the valve is made to open.

[00153] The present invention in accordance with a first apparatus embodiment, ~~as claimed in Claim 4~~ is fundamentally so-constituted so that a device for water hammerless opening of a fluid passage ~~it~~ comprises a valve

body, an actuator to drive the valve body, a vibration sensor removably fixed to the pipe passage on the upstream side of the valve body, an electro-pneumatic conversion control device to which ~~a~~the valve opening/closing command signal is inputted and with which the actuator operating pressure  $P_a$  inputted to the actuator is controlled by ~~a~~the control signal  $S_c$  stored in ~~a~~the data storage part in advance, and a computation control device equipped with a comparison computation circuit to which ~~a~~the vibration detecting signal  $P_r$  from the afore-mentioned vibration sensor, ~~a~~the step pressure setting signal  $P_s$  to be supplied to the actuator, ~~a~~the step pressure holding time setting signal  $T_s$ , and ~~a~~the permissible upper limit vibration pressure setting signal  $P_{rm}$ —

6

are inputted, and with which the afore-mentioned vibration detecting signal  $P_r$  and the permissible upper limit vibration pressure setting signal  $P_{rm}$  are compared, and the afore-mentioned step pressure setting signal is adjusted, thus outputting the control signal  $S_c$  consisting of the afore-mentioned holding time setting signal  $T_s$  and adjusted step pressure setting signal  $P_s$  to the data storage part of the afore-mentioned electro-pneumatic conversion control device.

[00164] The present invention in accordance with a second apparatus embodiment, which further modifies the first apparatus embodiment, as claimed in Claim 5 according to Claim 4 is ~~so~~ constituted so that ~~thea~~ a computation control device comprises a step pressure setting circuit, a holding time setting circuit, a permissible upper limit vibration pressure setting circuit, a vibration pressure detecting circuit and a comparison computation circuit; and, when the vibration

detecting signal  $P_r$  exceeds the permissible upper limit vibration pressure setting signal  $P_{rm}$  immediately after the actuator operating signal is step-changed, the step pressure setting signal  $P_s$  is adjusted toward the rising direction, and when the vibration detecting signal  $P_r$  exceeds the permissible upper limit vibration pressure setting signal  $P_{rm}$  immediately after the actuator operating pressure is made to zero from the intermediate step operating pressure, the step pressure setting signal  $P_s$  is adjusted toward the lowering direction.

[00175] The present invention in accordance with a third apparatus embodiment, which further modifies the first apparatus embodiment,~~as claimed in Claim 6 according to Claim 4 is so~~ constituted so that an electro-pneumatic conversion device comprises a data storage part that~~which~~ stores the control signal  $S_c$  from the computation control device, a signal conversion part and an electro-pneumatic conversion part; the \_-

7

actuator operating pressure control signal  $S_e$  is outputted from the signal conversion part to the electro-pneumatic conversion part based on the control signal  $S_c'$  stored in the data storage part in advance so that~~with which~~ no water hammer is caused.

[00186] The present invention in accordance with a fourth apparatus embodiment~~as claimed in Claim 7~~ is fundamentally ~~so~~ constituted so that a device for water hammerless opening of a fluid passage~~it~~ comprises an actuator operating type valve installed on the fluid passage, an electro-pneumatic conversion device to supply a~~the~~ 2-step actuator operating pressure  $P_a$  to the actuator operating type valve, a vibration sensor removably fixed to the pipe



passage on the upstream side of the afore-mentioned actuator operating type valve, and a tuning box to which the vibration detecting signal  $P_r$  detected through the vibration sensor is inputted, and from which the control signal  $Sc$  is outputted to the electro-pneumatic conversion device to control the step operating pressure  $Ps'$  of the afore-mentioned 2-step actuator operating pressure  $Pa$  ~~is outputted to the electro-pneumatic conversion device, and to~~ output the 2-step actuator operating pressure  $Pa$  of the step operating pressure  $Ps'$ , which makes the vibration detecting signal  $P_r$  nearly zero, from the electro-pneumatic conversion device by adjusting said control signal  $Sc$ .

[00197] The present invention in accordance with a fourth method ~~embodiment as claimed in Claim 8~~ is fundamentally ~~so~~ constituted so that, with the method for opening a fluid passage for which a vibration sensor is removably fixed on the upstream side of the actuator operating type valve installed on the fluid passage, and the vibration detecting signal  $P_r$  is inputted to the tuning box, and then, the control signal  $Sc$  from the tuning box is inputted to the electro-pneumatic conversion device, thus the \_-

8

2-step actuator operating pressure  $Pa$  generated in the electro-pneumatic conversion device by the afore-mentioned control signal  $Sc$  ~~is being~~ supplied to the actuator so that the actuator operating type valve is made to open in the 2-step operation, the 2-step actuator operating pressure  $Pa$  ~~to be~~ supplied to the actuator and the vibration detecting signal  $P_r$  are compared for the relative relation of the two, and if the vibration is generated at the time when the first step actuator operating pressure  $Pa$  rises, the step operating pressure  $Ps'$  is lowered,

and if ~~the~~-vibration is generated at the time when the second step actuator operating pressure  $P_a$  rises, the step operating pressure  $P_s'$  is raised, and the step operating pressure  $P_s'$ , of the step operating pressure  $P_a$  to make the vibration detecting signal  $P_r$  nearly zero, is determined by repeating a plurality ~~number of~~ adjustments of raising or lowering the afore-mentioned step operating pressure  $P_s'$  so that the afore-mentioned actuator operating type valve is ~~opened~~made open based on the data on the control signal  $Sc$  when the 2-step operating pressure  $P_a$  of the step operating pressure  $P_s'$  is outputted from the electro-pneumatic conversion device to make ~~the~~-generation of said-vibration nearly zero ~~is outputted from the electro-pneumatic conversion device~~.

[002048] The present invention in accordance with a fifth method ~~embodiment as claimed in Claim 9~~ is fundamentally ~~so~~ constituted so that, using~~with~~ the method for opening a fluid passage for which a vibration sensor is removably fixed on the upstream side of the actuator operating type valve installed on the fluid passage, ~~and the~~ vibration detecting signal  $P_r$  is inputted to the tuning box, and then, the control signal  $Sc$  from the tuning box is inputted to the electro-pneumatic conversion device. T, ~~thus~~, the 2-step actuator operating pressure  $P_r$  generated by~~in~~ the electro-pneumatic \_

9

conversion device by the afore-mentioned control signal  $Sc$  ~~being~~is supplied to the actuator so that the actuator operating type valve is made to open in the 2-step operation, and the 2-step actuator operating pressure  $P_a$  ~~to be~~ supplied to the actuator and the vibration detecting signal  $P_r$  are compared for the relative relation of the two, and if ~~the~~-vibration is generated at the time when the first step

actuator operating pressure  $P_a$  drops, then the step operating pressure  $P_s'$  is raised, and if ~~the~~ vibration is generated at the time when the second step actuator operating pressure  $P_a$  drops, then the step operating pressure  $P_s'$  is lowered, and the step operating pressure  $P_s'$  of the step operating pressure  $P_a$  is determined to make the vibration detecting signal  $P_r$  nearly zero ~~is determined~~ by repeating a plurality ~~number~~ of adjustments of raising or lowering of the afore-mentioned step operating pressure  $P_s'$  so that the afore-mentioned actuator operating type valve is made opened based on the data on the control signal  $S_c$  when the 2-step operating pressure  $P_a$  of the step operating pressure  $P_s'$  is outputted from the electro-pneumatic conversion device to make the generation of ~~said~~ vibration nearly zero ~~is outputted from the electro-pneumatic conversion device~~.

[002149] The present invention in accordance with a sixth method embodiment, which further modifies the fourth and fifth method embodiments, ~~as claimed in Claim 10 according to Claim 8 or Claim 9~~ is ~~so~~ made so that the vibration sensor and tuning box can be removed after the data on the control signal  $S_c$ , at the time of outputting the 2-step operating pressure  $P_a$  with which the generation of vibration is nearly zero, are ~~were~~ inputted to the memory storage of the electro-pneumatic conversion device.

[00229] The present invention in accordance with a seventh method embodiment, which further modifies the fourth and fifth method embodiments, ~~as claimed in Claim 11 according to Claim 8 or Claim 9~~ is ~~so~~ made so that the vibration sensor is provided at a ~~the~~ position on the upstream side within 1000mm from the place where the actuator operating type \_-

valve is installed.

[00234] The present invention in accordance with an eighth method embodiment, which further modifies the fourth and fifth method embodiments,~~as claimed in Claim 12 according to Claim 8 or Claim 9~~ is ~~so-made~~ so that the step operating pressure holding time  $t$  of the 2-step operating pressure  $P_a$  is set at less than 1 second.

[00242] The present invention in accordance with a ninth method embodiment~~as claimed in Claim 13~~ is ~~so-made~~ so that, ~~employing~~with the method with which a fluid is supplied to the fluid passage on the downstream side by opening the fluid passage by means of the actuator operating type valve installed on the fluid passage and having a nearly constant internal pressure therein, a chemical solution is used for ~~a~~-fluid, and firstly, the valve body is moved toward ~~the~~ direction of ~~the~~-valve opening by increasing or decreasing the afore-mentioned driving input to the actuator to the prescribed set value, and the actuator driving input is held at the afore-mentioned set value for a short period of time, and second~~then~~, ~~the~~said driving input is further increased or decreased to make the valve in a state of full opening so that a-water hammer does not occur at the time ~~of~~-the valve isbeing opened.

[00253] The present invention as claimed in Claim 14 according to Claim 13 is ~~so-made~~ so that the time the actuator driving input is to be held at the set value ~~for a short period of time~~ is made to be less than 1 second, and the pressure rise value of the fluid passage is made to be within 10% of the pressure value before the valve is ~~made~~-opened.

### Effects of the Invention

[00264] ~~Employing~~With the method of the present invention, it is made possible to abruptly openthat a fluid passage is ~~abruptly opened~~ in an extremely short period of time (e.g., within 300~1000m sec.) ~~and~~ without causing a water hammer because the valve can be \_

44

opened in ~~at~~the manner that, in the case wherethe fluid pressure is constant, the driving force to the actuator is held at the set value, to move the valve body to the prescribed position and to halt once for a short period of time. ~~Then to halt,~~ and then, the valve body is moved to the full opening position, thus making the set value for the afore-mentioned driving force atthe value in the appropriate range.

[00275] ~~T~~With the water hammerless opening device, according to the present invention, it is ~~so~~constituted so that water hammerless valve opening is achieved by a vibration sensor 18 that isbeing removably fixed to the pipe passage L1, wherein the vibration detecting signal Pr is detected by the vibration sensor 18 and isbeing fed back to the computation control device 16, and the actuator operating pressure ~~to be~~applied to the actuator 11 of the valve body 10 is controlled through the mediation of the electro-pneumatic conversion control device 17 ~~being controlled~~.\_\_

\_\_\_\_\_As a result, without there being a stroke position detecting device being installed on the valve body 10, or without atthe pressure detector being ~~left~~ attached to the pipe passage L1, water hammerless opening can be achieved,



and once the optimum conditions on water hammerless valve opening (that is, the conditions on the control of the actuator operating pressure  $P_a$ ) for the subjected pipe passage  $L_1$  is determined, the vibration sensor 18 and computation control device 16 can be removed so that they can be used for other pipe passages, thus making it extremely advantageous economically.

[00286] Furthermore, in accordance with the water hammerless opening device for the fluid passage of ~~according to~~ the present invention, ~~it is so made~~ that a vibration sensor 18 is installed in the vicinity of the valve body 10 on the pipe passage under an ~~the~~ —

42

actual operating condition, and the valve body 10 is actually operated for opening/closing by applying the prescribed 2-step actuator operating pressure  $P_a$  to the actuator 11 of the valve body 10 from the electro-pneumatic conversion device 20 so that an ~~the~~ optimum value of the step operating pressure  $P_s'$  of the afore-mentioned 2-step actuator operating pressure  $P_a$  is determined through the actual operation of the valve body 10, and the determined actuator operating pressure  $P_a$  is stored by ~~at~~ the storage device of the electro-pneumatic conversion device 20. —

————As a result, ~~It is~~ makes possible to abruptly open that the valve body 10 both reliably ~~is abruptly opened surely~~ and promptly and without causing a water hammer on the fluid passage by using ~~with~~ the actuator operating pressure  $P_a$  off ~~from~~ the electro-pneumatic conversion device 20.

[00297] In addition, ~~the~~ selection and setting (tuning) of the afore-mentioned 2-step actuator operating pressure  $P_a$  can be easily performed through the

actual operations of the valve body 10 over 5~6 times. Also, by applying the actuator operating pressure  $P_{a1}$  having the appropriate step operating pressure  $P_{s'1}$  to the actuator 11, the ~~value in~~ amplitude of the pressure vibration at the time of the valve body 10 ~~is being~~ actually opened for the first time can be suppressed ~~to at~~ at the lower value, thus making it possible to accurately determine in advance what is ~~that~~ the optimum value of the afore-mentioned actuator operating pressure  $P_a$  ~~is determined accurately in advance without adversely affecting the pipe passage being adversely affected.~~

[003028] Furthermore, by utilizing a personal computer, it ~~is becomes~~ possible to perform ~~that the~~ selection and setting (tuning) of the afore-mentioned 2-step actuator \_-

43

operating pressure  $P_a$  ~~both is performed extremely easily at ease and promptly,~~ and also so that the water hammerless opening device is manufactured at lower cost.

#### Brief Description of Drawings

[003129] Figure 1 is a circuit diagram of the testing device used for detecting the occurrence of a water hammer on the fluid passage.

[0032] Figure 2 is an explanatory drawing to illustrate an electro-pneumatic conversion device used for the testing device, wherein (a) is a basic block diagram, and (b) is a block diagram.

[0033] Figure 3 is a graph diagram to illustrate the relationship between an input signal  $I$  (input voltage  $V$ ) and an output pressure  $P_a$  ( $\text{kgf/cm} \cdot \text{G}$ ) of the

electro-pneumatic conversion device 5.

[0034] Figure 4 is a ~~graph~~diagram ~~to illustratinge~~ illustrating ~~with the~~ multi-step opening in which the internal pressure  $P_1$  of the pipe passage 1 is made constant, and to illustrate the state of vibration changes in the pipe passage  $L_1$  on the upstream side of the valve in the case where the supply pressure  $P_a$  to the actuator is ~~made~~ changed, wherein (a) shows the case where  $P_a$  is opened directly from  $0\text{kgf/cm} \cdot G$  to  $5\text{kgf/cm} \cdot G$ , and (b) shows the case where  $P_a$  is ~~changed~~dropped from  $0\text{kgf/cm} \cdot G$  to  $3.1\text{kgf/cm} \cdot G$  and then to  $5.0\text{kgf/cm} \cdot G$ .

[0035] Figure 5 is a ~~graph~~diagram ~~to illustratinge~~ illustrating how the internal pressure  $P_1$  of the pipe passage changes at the multi-step type opening ( $P_a=0 \rightarrow 2.5 \rightarrow 5\text{kgf/cm} \cdot G$ ) in the case where the tank pressure (the internal pressure  $P_1$  of the pipe passage) is made to changed, wherein (a) shows the case where the internal pressure  $P_1$  of the tank =  $0.245\text{MPa} \cdot G$ , (b)  $P_1 = 0.255$  and (c)  $P_1 = 0.274$  respectively.

44

[0036] Figure 6 is an enlarged view of Figure 5(c).

[0037] Figure 7 is a ~~graph~~diagram ~~to illustratinge~~ illustrating the relationship between the internal pressure  $P_T$  of the tank and the actuator operating pressure  $P_a$  so as to prevent a water hammer using~~with~~ the multi-step valve closing, wherein (a) shows the case where the internal pressure of the tank =  $0.098\text{MPa}G$ , (b)  $0.196\text{MPa}G$  and (c)  $0.294\text{MPa}G$ , respectively.

[0038] Figure 8 is an explanatory drawing ~~to illustratinge~~ illustrating the relationship between the actuator operating pressure  $P_a$  and the time of detecting the vibration in Figure 7.



[0039] Figure 9 is a whole block diagram of ~~at~~ the first embodiment of the water hammerless opening device for the fluid passage according to the present invention.

[0040] Figure 10 is an explanatory drawing ~~to illustrating~~ the control of the actuator operating pressure  $P_a$  (Figure 10a) and one example of the occurrence of the vibration (Figure 10b) ~~using~~ with the water hammerless opening device ~~of~~ in Figure 9.

[0041] Figure 11 is a whole system diagram of the water hammerless opening device ~~with respect in regard to~~ ~~at~~ the second embodiment according to the present invention.

[0042] Figure 12 is an overview of ~~at~~ the PC screen display of a tuning box.

[0043] Figure 13 is a schematic block ~~—schematic~~ diagram of an electro-pneumatic conversion device.

[0044] Figure 14 is a flow chart of auto-tuning operations.

[0045] Figure 15 is an explanatory drawing for the relationship between the driving ~~—~~

15

pressure  $P_a$  and the vibration that occurred in ~~the~~ auto-tuning operations.

[0046] Figure 16 is a graph ~~diagram to illustrating~~ the relationship between the step pressure holding time  $t$  of the driving pressure  $P_a$  in steps and the pressure rising value  $\Delta P$ .

[0047] Figure 17 is a system diagram ~~to illustrating~~ the case where ~~that~~ the chemical solution supply method according to the present invention is applied to ~~at~~ the single wafer processing cleaner of ~~the~~ semiconductor manufacturing

equipment.

### List of Reference Characters and Numerals

[004830] PT Internal pressure of a water tank

L<sub>1</sub> Pipe passage on the upstream side of a valve

P<sub>1</sub> Internal pressure of a pipe passage

P<sub>a</sub> Actuator operating pressure

P<sub>ao</sub> Air supplying pressure

$\Delta G$  Valve stroke

S Valve opening/closing command signal

1 Water tank

2 Source for pressurizing a water tank

3 Pressure sensor

4 Valve

4a Actuator

5 Electro-pneumatic conversion device

6 Valve driving gas source

7 Signal generator

46

8 Storage oscilloscope

10 Valve body

11 Actuator

16 Computation control device

17 Electro-pneumatic conversion control device

- 18     Vibration sensor
- 19     Tuning box
- 20     Electro-pneumatic conversion device
- T     Opening time detecting signal
- P<sub>1</sub>     Pressure detecting signal
- PM     Permissible pressure rising value setting signal
- Pr     Vibration detecting signal
- P<sub>rm</sub>     Permissible upper limit vibration pressure setting signal
- Ps     Step pressure setting signal
- Ts     Step pressure holding time setting signal  
           (Opening time setting signal)
- Sc     Control signal
- Se     Actuator operating pressure control signal
- So     NO-NC switching signal for a valve
- t     Step pressure holding time
- Ps'     Step operating pressure
- A<sub>0</sub>     Fluid supply system
- B<sub>0</sub>     Single wafer processing cleaner

17—

- W     Wafer
- A · B · C · D     Chemical solutions to be mixed

Detailed Description of the Invention~~Practice of the Invention~~

[004934] In order to investigate how a water hammer is caused in the liquid

supply system of ~~the~~ semiconductor manufacturing equipment, the inventors of the present invention have observed ~~the~~ pressure changes in the fluid flow passage at the time when the flow passage is switched from ~~the~~ full closing to ~~the~~ full opening by employing a pneumatic pressure operating diaphragm.\_\_\_\_

\_\_\_\_Figure 1 is a circuit diagram of the testing device employed for the afore-mentioned investigation. Referring to Figure 1, 1 designates a water tank, 2 is a source for pressurizing the water tank, 3 is a pressure sensor, 4 is a valve, 5 is an electro-pneumatic conversion device, 6 is a valve driving gas source, 7 is a signal generator and 8 is a storage oscilloscope.

[005032] The afore-mentioned water tank 1, having a capacity of 30 liters, is of a hermetically sealed structure and stores about 25 liters of the fluid (water of 25°C) therein.\_\_\_\_

\_\_\_\_Also, the water tank 1 is pressurized by N<sub>2</sub> from the pressurizing source 2, and the pressurization can be adjustedable as desired within the range of 100~300KPaG.

[005133] The afore-mentioned pressure sensor 3 is capable of detecting water pressure on the upstream side of the valve 4 with high sensitivity. A diffusion semiconductor type pressure sensor iswas employed in the testing device.

[005234] A diaphragm type pneumatic valve is used for the afore-mentioned\_

48

valve 4, and specifications thereof are as follows: fluid inlet pressure 0.1MPa, fluid outlet pressure 0.3MPa, fluid temperature 10~100°C, the CV value 0.27, operating air pressure 3~0.6MPa, materials of liquid-contacting parts (PTFE for the valve body and PTFE for the diaphragm), and the inside diameter of the

passage is 4mm. \_\_

\_\_\_\_SpecificallyNamely, thesaid valve 4 is a pneumatically operating diaphragm valve whose~~ie~~h valve body is a normally-closed (N.C.) type synthetic resin made diaphragm. The diaphragm valve body rests~~is~~-rested on the valve seat all of the time due to~~by~~ the elastic force of a~~the~~ spring (not shown in the figure) so that the valve is maintained in a closed state. W~~r~~-while the actuator 4a is operated by~~with~~ the supply of ~~the~~-operating pneumatic pressure, the~~s~~ resulting ~~isn~~ that the diaphragm valve body moving~~is~~-moved away from the valve seat and maintaining ~~amaintained in~~-a state in which the valve is kept open. \_\_

\_\_\_\_Accordingly, to open thesaid normally-closed type pneumatically operating type diaphragm valve, it is required that ~~the~~-operating pneumatic pressure be~~is~~ supplied to the actuator 4a. \_\_

\_\_\_\_According to the present invention, it goes without saying~~there is no~~ need to say that a normally-closed type pneumatically operating diaphragm valve can be replaced by a normally-open (N.O.) type pneumatically operating diaphragm valve. In such a~~this~~ case, the normally-open type valve is maintained in a state of being closed by raising the operating pneumatic pressure ~~to be~~-supplied to the actuator 4a.

[005335] The afore-mentioned electro-pneumatic conversion device 5 is used to supply driving pressure (pneumatic pressure), corresponding to the input signal \_-

49

for directing the degree of ~~the~~-valve opening, to the actuator 4a for the valve 4.

As part of~~With~~ the testing device of Figure 1, the electro-pneumatic conversion

device 5, which is constituted as shown in Figure 2, ~~is~~has been employed. \_\_

\_\_\_\_\_~~In particular~~Namely, when the input signal I is inputted to the control circuit A<sub>2</sub>, an air supply electromagnetic valve B<sub>2</sub> opens so that a part of the supply pressure C<sub>2</sub> is supplied to the actuator 4a ~~offer~~ the valve 4 as an output pressure Pa through the air supply electromagnetic valve B<sub>2</sub>. \_\_

\_\_\_\_\_~~The~~ output pressure Pa is fed back to the control circuit A<sub>2</sub> through the mediation of the pressure sensor E, thus ~~an~~the operations for correction ~~is~~ being effected until the ~~outputted~~ pressure Pa reaches the output pressure Pa corresponding to the input signal I. Referring to Figure 2, F designates an exhaust electromagnetic valve, G ~~is an~~ exhaust, H ~~is a~~ power source, and J ~~is an~~ output signal corresponding to the input signal I. ~~The~~Said output signal J (that is, an input signal I) is inputted to the storage oscilloscope 8 as the input voltage as described later.

[005436] Figure 3 is a diagram ~~to~~illustrating the relationship between the value of the input signal I (input voltage V) of the afore-mentioned electro-pneumatic conversion device 5 and the output pressure Pa. Figure 3It shows that the valve 4 is held in a state of full opening ~~when~~with the input voltage ~~is~~ 5V (operating air pressure P = approximately 5kgf/cm<sup>2</sup> · G).

[005537] A compressor is employed for the afore-mentioned valve operating air source 6 to supply gasair with the prescribed pressure. And, the afore-mentioned signal generator 7 generates the input signal I<sub>1</sub> and the like, to the \_-

20

electro-pneumatic conversion device 5, and the like, so that the desired voltage

output is outputted to the electro-pneumatic conversion device 5 as the input signal I.\_\_\_\_

\_\_\_\_\_Furthermore, the pressure detecting signal  $P_1$  (voltage  $V_1$ ) in the pipe passage  $L_1$  on the upstream side from the pressure sensor 3, and the input signal I (input voltage  $V$ ) to the electro-pneumatic conversion device 5 are inputted to the afore-mentioned storage oscilloscope 8 in order, to observe and record the changes in the pressure  $P_1$  in the pipe passage  $L_1$ , the changes in the input signal (input voltage  $V_1$ ) and the like. The storage oscilloscope 8, which has its time-axis is graduated in 500m sec/1, is ~~has been employed in~~ for the testing device.

[005638] Referring to Figure 1, the internal pressure  $P_T$  of the water tank 1 is held at a specified pressure of 0.172MPa · G, and the operating air pressure  $P_a$  of 0.490MPa · G is supplied to the actuator 4a, thus making the valve 4 move to a state of full opening from a state of full closing. In this case ~~Here~~, the inside diameter of the pipe passage  $L_1$  was 4.0mm, the length approximately 1.0m, and the flow rate  $Q$  of the water was approximately 3.45 liters/min. Figure 4 shows changes in the supply air pressure  $P_a$  to the actuator 4a offer the valve 4 and in the internal pressure  $P_1$  of the pipe passage  $L_1$  on the upstream side observed by the storage oscilloscope.\_\_\_\_

\_\_\_\_\_As apparent from ~~the afore-shown~~ Figure 4(a), ~~there were shown~~ changes in ~~the~~ vibration output, with the amplitude of approximately maximum 12V, were shown ~~as in Figure 4(a)~~ when the valve 4 was fully opened through the process of 0 (fully closed)→0.490MPa · G (fully opened).

[005739] On the other hand ~~contrary~~, in the case where the supply pressure  $P_a$



is made to changed as 0 (fully closed)

24

→0.29 MPa · G (mid-position or intermediate position)→0.490 MPa · G (fully opened) (Figure 4(b)), ~~there were seen nearly no changes in the vibration~~ of the pipe passage were observed, thus ~~demonstrating~~resulting in that the water hammer effect can be is perfectly prevented.

[005840] In particular Namely, it is apparent that, if the internal pressure  $P_1$  of the pipe passage  $L_1$  is kept constant, then (1) the fluid passage can be opened, without causing a water hammer, in about 500~1000m sec by opening the valve instantaneously from a state of full closing to a certain degree of opening (i.e., mid-position or intermediate position), and then making the valve move to a state of full opening after a short lapse of time, and (2) the water hammer cannot be prevented if the afore-mentioned initial halt position of the valve body, that is, the degree of valve opening, is either greater or smaller than a specific value.

[005944] Figure 5(a), (b), (c) show ~~the~~ pressure changes in the pipe passage on the upstream side of the valve 4 when the step pressure  $P_s$  is made to changed from 0.245MPa · G to 0.255MPa · G to 0.274MPa · G, and the pressure  $P_a$  of the actuator is made to changed as 0→0.245→0.49MPa · G, to open the valve 4 fully in 100m sec.

[006042] Figure 6 is an enlarged view of what the afore-shown Figure 5(c) is enlarged. It becomes apparent that ~~the~~ vibration of the pipe passage  $L_1$  on the upstream side can be made nearly zero by fully opening the valve 4 with at the 2-step operations to raise the pressure  $P_a$  of the actuator in the order of 0→0.294→0.490MPa · G in about 1000m sec.



[006143] Figure 7(a), (b), (c) show ~~what surveyed on the~~ relationship observed between the step pressure  $P_s$  and the vibration pressure in the pipe passage  $L_1$  on the upstream side in the cases where the internal pressure of the tank is made to be 0.098, 0.196 and 0.294MPa  $\cdot G_1$  respectively. Thus, it becomes apparent that there\_ –

22

exists ~~at the~~ step pressure  $P_s$  ~~that which~~ minimizes the vibration pressure for each case. In these cases Here, a holding time of the step pressure is ~~made to be~~ 1000m sec.

[006244] Figure 8 is an explanatory drawing of the supply pressure  $P_a$  to the actuator 4a in the test of the afore-shown Figure 7, and shows the relationship of ~~the positioning of~~ the step pressure  $P_s$  and the first step (point A) and the second step (point B).

#### [The First Embodiment of a Water Hammerless Opening Device]

[006345] Figure 9 and ~~Figure 10~~ illustrates the basic block configuration of the first embodiment of a water hammerless opening device for the fluid passage according to the present invention. The device is mainly used when it is found difficult to mount a pressure detector, such as 3,  ~~$P_e$~~  on the pipe passage  $L_1$  on the upstream side ~~that which~~ has been already installed, or to mount a valve stroke detector (a position detector) on the valve body 10.

[006446] Referring to Figure 9 and Figure 10, ~~the said~~ water hammerless opening device is made by assembling a valve body 10, an actuator 11, an electro-pneumatic conversion control device 17, a computation control device 16

~~that~~which makes possible the control possible over the step switching of the actuator operating pressure  $P_a$ , and the pressure holding time  $T_s$  after having been switched and the like. A, ~~and~~ a vibration sensor 18 is removably fixed to the pipe passage  $L_1$  on the upstream side so that the conditions of opening of the valve body 10, which make water hammerless opening possible, are set and stored beforehand by appropriately selecting the step switching of the actuator operating pressure  $P_a$  (switching from 0 to the step pressure  $P_s$  in Figure 10(a)) applied to the actuator—

23

11 of the valve body 10 and also the holding time  $T_s$  of the step pressure  $P_s$ .

[006547] More specifically Namely, with respect to Figure 9 and Figure 10, 16 designates the a computation control device, 17 is the an electro-pneumatic conversion control device, 18 is a vibration sensor, 6 is a valve driving gas source, 10 is a valve body and 11 is an actuator. The driving pressure  $P_{ao}$  (approximately 0.6MPa in this embodiment) from the valve driving gas source is converted to the step operating pressure  $P_a$  as shown in Figure 10(a) by the electro-pneumatic conversion control device 17, and then is applied to the actuator 11.

[006648] The actuator operating pressure  $P_a$  applied to the actuator 11, and its holding time  $T_s$ , are controlled by the control signal  $S_c$  from the computation control device 16 determined beforehand by the operating test wherein opening of the valve body was conducted for each pipe passage  $L_1$  on the upstream side of the valve ~~beforehand~~—in a the manner described later. TheSaid vibration sensor 18 and computation control device 16 are removed

from the pipe passage L<sub>1</sub> on the upstream side upon completion of the selection of selecting the afore-mentioned control signal Sc by employing the operating test for opening the valve body 10.

[006749] ~~T~~Namely, the afore-mentioned computation control device 16 is equipped with a setting circuit 16a for receiving the step pressure setting signal Ps, a setting circuit 16b for receiving the pressure holding time setting signal Ts, a setting circuit 16c for receiving the permissible upper limit vibration pressure setting signal P<sub>rm</sub>, a pipe passage vibration pressure detecting circuit 16d, a comparison computation circuit 16e, and the like. ~~T~~, and to which the vibration detecting signal Pr<sub>1</sub> by which changes in the internal pressure P<sub>1</sub> detected by the vibration sensor 18 at the time of opening of –

24

the valve body 10 are considered, the step pressure setting signal Ps, the step pressure holding time setting signal Ts, and the permissible upper limit vibration pressure setting signal P<sub>rm</sub> are inputted, respectively, to the computation control device 16.

[006850] ~~T~~And, the vibration detection signal Pr and the permissible upper limit vibration pressure setting signal P<sub>rm</sub> are compared at the comparison computation circuit 16e. When athe difference is found between them, as described later, the step pressure setting signal Ps is corrected so that the control signal Sc includes theing-said corrected step pressure-setting pressure setting signal Ps and the holding time setting signal Ts. The control signal Sc is outputted to the data storing part 17a of the electro-pneumatic conversion control device 17.

[006954] Also, the afore-mentioned electro-pneumatic conversion control device 17 is equipped with a data storage part 17a, a signal conversion part 17b (i.e., a signal generator 7), an electro-pneumatic conversion part 17c (i.e., an electro-pneumatic conversion device 5), and the like. The actuator operating pressure  $P_a$  supplied to the actuator 11 is switched and converted in the steps, as shown in Figure 10(a), by the actuator operating pressure control signal  $S_e$  from the signal conversion part 17b that is being inputted to the electro-pneumatic conversion part 17c.\_\_\_\_

\_\_\_\_\_The switching signal  $S_o$  ~~corresponding to~~ correspond to the valve opening/closing command signal  $S$  and the operating situation ( $NO = \text{normally open}$  or  $NC = \text{normally closed}$ ) of the valve body 10 is inputted to the said electro-pneumatic conversion control device 17.

[007052] Referring to Figure 9, firstly a vibration sensor 18 is fixed to the pipe passage. Next, the appropriate step pressure setting signal  $P_s$ , step pressure  
25

holding time setting signal  $T_s$ , and permissible upper limit vibration pressure setting signal  $P_{rm}$ , are inputted to the computation control device 16, and the valve body switching signal  $S_o$  of the electro-pneumatic conversion control device 17 and the actuator operating fluid supply pressure  $P_{ao}$  are appropriately set.

[007153] Then, by inputting the valve opening/closing command signal  $S$ , the actuator operating pressure  $P_a$ , for example, like a form shown in Figure 10(a), is supplied to the actuator 11 of the valve body 10.\_\_\_\_

\_\_\_\_\_Now, when the actuator operating pressure  $P_a$  is raised from 0 to  $P_s$  at

a-time  $t_1$ , the fluid passage of the valve body 10 is opened up to its mid-position, and the valve body 10 is in thea state of full opening whenby the actuator operating pressure  $P_s$  isbeing made to be  $P_{max}$  at a-time  $t_2$  when, further, the set holding time has elapsed.

[007254] Meantime, if the internal pressure  $P_1$  of the pipe passage  $L_1$  changes due to the occurrence of a water hammer, the changes are detected by the vibration sensor 18 and the vibration detecting signal  $P_r$  is inputted to the computation control device 16.\_\_\_\_

————In the computation control device 16, the detecting signal  $P_r$  and permissible upper limit vibration pressure setting signal  $P_{rm}$  are compared, and when it is found that there occurs no vibration or the vibration is within tolerance at a position  $A_1$  (time  $t_1$ ), but the vibration exceeds tolerance  $P_{rm}$  at a position  $A_2$  (time  $t_2$ ), the step pressure setting signal  $P_s$  is corrected to raise the actuator operating pressure a little so that the corrected step pressure setting signal  $P_{s\_}$ .

26

and corresponding holding time setting signal  $T_s$  ~~thereof~~, are outputted as the control signal  $S_c$  from the computation control device 16 to the electro-pneumatic conversion control device 17, and the same operating tests for opening the valve body are thereafter repeated ~~thereafter~~.

[007355] Conversely, when it is found that ~~the~~ vibration occurred at a position  $A_1$  (time  $t_1$ ) exceeds the permissible upper limit vibration pressure setting signal  $P_{rm}$ , the setting signal  $P_s$  is corrected to lower the afore-mentioned step pressure setting signal  $P_s$  a little, and outputted as the control signal  $S_c$  from the computation control device 16 to the electro-pneumatic

conversion control device 17, and the same operating tests for opening the valve body 10 are repeated thereafter.

[007456] Through repeating operating tests as described stipulated in the above paragraphs [006446] and [006749], the intermediate operating pressure  $P_s$  (the step pressure setting signal  $P_s$ ) for the actuator 11, required for water hammerless opening of the pipe passage  $L_1$  equipped with a vibration sensor 18, is selected for the specified step pressure holding time setting signal  $T_s$  (the valve opening time  $T_s$ ). The selected control signal  $Sc$ , by which the optimum step pressure setting signal  $P_s$  and holding setting time  $T_s$  will for not causing a water hammer, are given is stored in the data storage part 17a of the electro-pneumatic conversion control device 17, and the pipe passage  $L_1$  is opened from then on by controlling the actuator operating pressure  $P_a$  based on the stored control signal  $Sc$ .

[007557] In accordance with the embodiment in the afore-shown Figure 9 and Figure 10, the present invention is so made that the actuator operating pressure  $P_a$  is controlled in 2 steps. \_\_\_\_

27

However, it goes without saying ~~there is no need to say that~~ the invention can be switched in 3 steps or 4 steps when necessary. \_\_\_\_

\_\_\_\_ Normally, the step holding time setting signal  $T_s$  is set between 0.5~1 second. It also goes without saying ~~There is no need to say that~~ the shorter the said time  $T_s$  becomes, the more difficult it becomes to find the conditions for water hammerless opening.



[The Second Embodiment of a Water Hammerless Opening Device]

[007658] Figure 11 illustrates the second embodiment of the method of opening a fluid passage, and the water hammerless opening device for which the method is used, according to the present invention.\_\_\_\_

\_\_\_\_\_In Figure 11, L<sub>1</sub> designates a pipe passage, 10 is a valve body, 11 is an air actuator, 18 is a vibration sensor, 19 is a tuning box and 20 is an electro-pneumatic conversion device. The basic configuration as a water hammerless opening device is almost the same as that of the first embodiment shown in Figure 9.

[007759] The afore-mentioned tuning box 19 is for optimizing the actuator operating pressure  $P_a$  in 2 steps supplied to the air actuator 11 using by the vibration detecting signal  $P_r$ , provided by ~~from~~ the vibration sensor 18 mounted on the upstream side of the valve body 10 and which is ~~being~~ inputted as a feedback signal. The tuning box is for ~~to~~ detecting the occurrence of a water hammer from thesaid feedback signal  $P_r$  and is for ~~to~~ outputting the control signal  $S_c$  for the actuator operating pressure, to the electro-pneumatic conversion device 20. Specifically ~~Concretely~~, as described later, the optimal values for the step operating pressure  $P_s'$  of the actuator operating pressure  $P_a$  and the step operating pressure holding time  $t$ , as shown in Figure 15, are computed. T, thus, outputting ~~the~~ control signal  $S_c$  may be outputted to the electro-pneumatic conversion device 20, which will ~~to~~ make thesaid ~~the~~ -

28

actuator operating pressure  $P_a$  output from the electro-pneumatic conversion device 20 to the actuator 11.



[007860] ~~The~~Said tuning box 19 is equipped with a selector switch for switching the control signal  $S_c$  corresponding to the type of operation (N.O. or N.C.) of the air actuator 11 of the valve body 10.

[007964] Figure 12 shows one example of the PC screen display ~~that~~which forms ~~at~~the major part of the tuning box. The screen display is ~~so~~constituted ~~so~~ that a state of opening/closing of the valve body 10, the actuator operating pressure  $P_a$  to the air actuator 11, circumstances of the vibration of the pipe passage  $L_1$ , the step operating pressure  $P_s'$  and pipe vibration values, the condition setting for auto-tuning, the condition setting for manual opening/closing, the operation type of the valve body 10, and others information can be displayed on the screen.

[008062] The signal converter and electro-pneumatic converter are combined to make the afore-mentioned electro-pneumatic conversion device 20. As shown in Figure 13, the electro-pneumatic conversion device 20it comprises an air inlet electromagnetic valve  $B_2$ , an air outlet electromagnetic valve  $F$ , a pressure sensor  $E$ , a control circuit  $A_2$ , and others. Basically, ~~the~~its configuration is almost the same as those shown in Figures 2(a) and (b).

[008163] In particularNamely, ~~an~~the air pressure higher than 0.6MPa is supplied to the air inlet electromagnetic valve  $B_2$ , and ~~an~~the air pressure of 0~0.5MPa is outputted to the actuator 11 as the actuator operating pressure  $P_a$ . The control circuit  $A_2$  of ~~the~~said electro-pneumatic conversion device 20 is equipped with the substrate  $A_1$ , the outside input/output interface  $A_0$ , and others.

29\_\_

The outside input/output interface  $A_0$  is equipped with two connectors  $A_c$  and  $A_d$ .

A power supply source (DC24 or 12V), an opening/closing signal I (voltage input or non-voltage input) and a pressure monitor (0~5DCV · 0~981KPaG) are connected to the connector Ad, while ~~the~~ tuning box 19 is connected to the connector Ac.

[008264] Figure 14 shows the implementation flow of the auto-tuning in ~~the~~ said second embodiment. Figure 15 shows the relative relationship between the actuator operating pressure Pa applied to the actuator 11 and the occurrence of the vibration. —

—— As in the case of Figure 10, the 2-step actuator operating pressure, ~~in 2 steps~~ as shown in Figure 15, is applied as the actuator operating pressure Pa.

[008365] Referring to Figure 14, and as shown in Figure 11, the vibration sensor 18 is fixed at a prescribed position of the pipe passage L<sub>1</sub> (a position on the upstream side within about 1000mm from the valve body 10, or preferably a position of 100~1000mm away to the upstream side), and a tuning box 19 and an electro-pneumatic conversion device 20 are set, respectively. —

—— Next, the valve is held in a state of full closing for about 2 seconds (step S<sub>2</sub>) ~~by~~ with the input (step S<sub>1</sub>) of the auto-tuning start signal, and then the actuator operating pressure Pa is applied in 2 steps for conducting the control ~~being conducted~~ (step S<sub>3</sub>). As described later, the holding time t of the step operating pressure Ps' has been set between 0.5~1 sec.

[008466] The vibrations caused on the pipe passage L<sub>1</sub>, ~~when~~ the valve body 10 is opened, are detected and confirmed (step S<sub>4</sub>) by the vibration detecting signal Pr. —

from the vibration sensor 18, and a check is made to see whether the vibrations are caused at the point A<sub>y</sub> or at the point B<sub>y</sub> (step S<sub>5</sub>, step S<sub>6</sub>). When it is found that ~~the~~ vibrations are caused at the point A<sub>y</sub>, the step operating pressure Ps' of the actuator operating pressure Pa is reduced (step S<sub>7</sub>), while when it is found that the vibrations are caused at the point B<sub>y</sub>, the afore-mentioned step operating pressure Ps' is raised (step S<sub>8</sub>).

[008567] The actuator operating pressure Pa having the optimum step operating pressure Ps', with which no vibration is caused, is eventually obtained by repeating the control of ~~the~~ opening of the afore-mentioned valve body 10 (normally over 2 or 3 to 15 times). Then the valve body 10 is made to open by inputting the control signal Sc obtained through auto-tuning of the electro-pneumatic conversion device 20 to output the actuator operating pressure Pa in 2 steps, with which completely prevents the vibrations ~~are completely prevented, obtained through the auto-tuning to the electro-pneumatic conversion device 20.~~

[008668] The shorter is set the step operating pressure holding time t of the 2-step actuator operating pressure Pa, ~~in 2 steps~~ applied at the time of the afore-mentioned auto-tuning, the better. However, when using with a pneumatically operating actuator 11, it is desirable that the time t is less than 1 second.\_\_\_\_

\_\_\_\_~~From~~With afore-shown Figure 14 and Figure 15, an illustration the explanation is given for the case where ~~at that~~ the normally closed type pneumatically operating diaphragm valve is employed, and the valve of the valve body 10 ~~which valve is closed~~ and then is made to open by supplying the

actuator operating pressure  $P_a$ . However, it goes without saying~~there is no~~  
~~need to say~~ that a water hammerless opening can also be achieved by  
employing a~~the~~ normally open type pneumatically operating diaphragm valve so  
that~~and~~ reducing the \_-

34

actuator operating pressure  $P_a$  in 2 steps opens the valve. In this case, it  
should be noted that ~~the~~ adjustments of the step operating pressure  $P_a'$  of the  
actuator operating pressure  $P_a$  are the reverse of the case of when the  
afore-mentioned normally closed type pneumatically operating diaphragm valve  
is used. That is, when the vibrations are caused at the time when ~~of~~ the  
actuator operating pressure  $P_a$  in the first step is being reduced in the first step,  
the step operating pressure  $P_a'$  is then raised, while when the vibrations are  
caused at the time when ~~of~~ the actuator operating pressure  $P_a$  in the second  
step is being reduced, then the step operating pressure  $P_a'$  is lowered.

[008769] Figure 16 illustrates the~~a~~ relationship between the step operating  
pressure holding time  $t$  and the pressure rising value  $\Delta P$ (MPaG) when the  
pneumatic pressure operating valve (19.05mm) is employed, with which ~~the~~  
inner capacity remains unchanged at the time when the valve is opened or  
closed, ~~is employed~~, and 3 pipe passages with a~~the~~ liquid line of 0.098MPa,  
0.198MPa and 0.294MPa are opened with a~~the~~ operating pressure  $P_a$  having  
the actuator operating pressure  $P_a$  of  $0\text{MPaG} \rightarrow 0.294\text{MPaG} \rightarrow 0.490\text{MPaG}$   
in 2 steps. It has been determined~~known~~ that if the step operating pressure  
holding time  $t$  is made to be more than 1 second, the pressure rise  $\Delta P$  can  
reach nearly zero, and if  $t$  is made to be less than 0.5 second, the pressure rise

$\Delta P$  goes up.

[008870] Upon completion of the afore-mentioned auto-tuning, when the control signal  $Sc$ , which allows the water hammerless opening of the pipe passage  $L_1$  (that is, the control signal for outputting the actuator operating pressure in 2 steps which allows for the water hammerless opening), is determined, then data of the afore-mentioned control signal  $Sc$  (that is, the operating pressure  $Pa$ ) are \_-

32

transmitted to the electro-pneumatic conversion device 20 that, to stores the data separately. T, thus, the tuning box 19 and the vibration sensor 18 are no longer necessary and may be being removed from the system.

[008974] When it becomes necessary to urgently open that the valve body 10 is opened urgently, the 2-step actuator operating pressures  $Pa$ , in 2 steps which permit allows the water hammerless opening, are outputted from the electro-pneumatic conversion device 20 to the actuator 11 of the valve body 10 by employing using the data on the afore-mentioned control signal previously determined through the auto-tuning beforehand.

[009072] With respect to the embodiment in the afore-shown in Figure 11, when the actuator operating pressure  $Pa$  (the step operating pressure  $Ps'$  and the holding time  $t$  thereof) is determined upon completion of the auto-tuning operation, the data on the said operating pressure  $Pa$  are transmitted to the electro-pneumatic conversion device 20; thus, the vibration sensor 18 and the tuning box 19 are completely removed thereafter from the system. However, it goes without saying ~~there is no need to say~~ that the tuning box 19 may be is

downsized so that it can be integrated with the electro-pneumatic conversion device 20.

[009173] Figure 17 is a system diagram ~~to illustrating~~ how the method of supplying chemical solutions according to the present invention is applied to ~~at the~~ single wafer processing cleaner ~~that which~~ constitutes a semiconductor manufacturing facility. According to With Figure 17, A<sub>0</sub> designates a fluid supply system, 10 are valve bodies installed in the fluid supply system A<sub>0</sub>, B<sub>0</sub> is a single wafer processing cleaner, L<sub>0</sub> is a pipe passage, W is a wafer, A is a mixed chemical solution (ozonized ultra-pure water · the concentration of ozone 2~3ppm), B is a mixed chemical solution of hydrofluoric acid, hydrogen peroxide, ultra-pure water (mixing ratio 0.03:1:2), C is a –

33

mixed chemical solution of ammonium hydroxide, hydrogen peroxide, ultra-pure water (mixing ratio 0.05:1:5), and D is ultra-pure water. The fluid supply system A<sub>0</sub> in Figure 17 is constituted in the form like, for example, the afore-shown systems of Figure 1, Figure 9 or Figure 11. The system of Figure 17 ~~it~~ is so constituted that, firstly, the valve of the valve body 10 is moved in the direction of ~~the~~ valve opening through ~~the~~ mediation of the actuator (not illustrated) by a given degree, and next, the valve ~~it~~ is held as it is at the given degree of valve opening (i.e., mid-position or intermediate) for a short period of time, and then the valve is moved to the position of full opening so, ~~thus~~ the valve body 10 is fully opened.

[009274] The constitution and action of the fluid supply system A<sub>0</sub> are exactly the same as those in the systems of afore-shown Figure 1, Figure 9 or Figure 11.



Therefore, ~~further~~ the explanation of these alternate embodiments is omitted herewith.\_\_\_\_

\_\_\_\_The cleaning process of a wafer W is that, first, ~~ly~~ cleaning is performed ~~using~~ with the mixed chemical solution A, and next, the mixed chemical solution B is supplied, and then the mixed chemical solutions C and D are supplied in turn ~~as~~ by the valve body 10 ~~is~~ being switched through ~~the~~ mediation of the actuator.

[009375] At the time of ~~supplying~~ the chemical solutions A, B, C and D are supplied, it is desirable that the pressure rise value in the pipe passage L<sub>1</sub>, ~~occurring~~ ed when the valve body 10 is opened, is kept within 10% of the pressure value before the valve is opened. In order that the pressure rise value is kept within the afore-mentioned 10% limit, some adjustments are made for the driving input value to the afore-mentioned actuator and also for the corresponding holding time ~~thereof~~. The pressure rise value in the pipe passage L<sub>0</sub> can be kept within 10% of the steady state value by maintaining ~~making~~ the pressure rise value in the pipe passage L<sub>1</sub> within 10%.\_\_\_\_

34\_\_\_\_\_

Furthermore, with respect to the embodiment discussed above, ~~the~~ explanation is ~~provided~~ given only for the upper limit of the pressure rise value at the time of ~~the start of supplying of~~ mixed chemical solutions A, B, C and D (or at the time of the valve being opened) is started. However, it goes without saying ~~there is no need to say that there exists~~ an the upper limit for the pressure rise value for the pipe passage L<sub>1</sub> at the time of halting ~~the halt of supplying of~~ mixed chemical solutions A, B, C and D (or at the time of the valve being closed). Each valve



body 10 in Figure 17 is operated for closing so that the afore-mentioned pressure rise value is kept within the set value.

#### Feasibility of Industrial Use

[009476] The present invention is applicable not only to ~~the~~ supply pipes for water, steam, and the like, used in industries, but is also applicable to ~~the~~ supply pipes for household water/hot water. The present invention is also applicable to ~~the~~ supply pipes for fluids (gases and liquids) used in ~~the~~ semiconductor manufacturing plants, chemical plants, and the like. The present invention is particularly suited for application ~~applying~~ to chambers-, wafer cleaning devices or various types of etching devices used for semiconductor manufacturing.